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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 349

ECONOMIC GEOLOGY

OF THE

KENOVA QUADRANGLE

KENTUCKY, OHIO, AND WEST VIRGINIA

BY

WILLIAM CLAYTON STALEY

WASHINGTON
GOVERNMENT PRINTING OFFICE
1909

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ECONOMIC GEOLOGY OF THE KENOVA QUADRANGLE, KENTUCKY, OHIO, AND WEST VIRGINIA.

By WILLIAM CLIFTON PHALEN.

INTRODUCTION.

Importance of the area.—The Kenova quadrangle is of interest on account of its valuable deposits of coal and fire clay. Of less value are its iron ores, limestones, and building stones. It forms part of a much larger area in which during the last three or four decades there has been much activity in the mining of coal and in the mining and smelting of iron ores. The latter industry has been discontinued, but coal is still being mined. The clay industry in this region is small at present, but should have an important future on account of the amount of available raw material. (See Pl. I, in pocket.)

Location and area.—The Kenova quadrangle includes parts of Kentucky, Ohio, and West Virginia, the name Kenova being coined by combining abbreviations of these State names. Its exact position is shown on the accompanying key map (Pl. II). Far the greater part of its 938 square miles is within Kentucky, including the whole of Boyd County, the larger part of Lawrence, and parts of Carter, Greenup, and Elliott counties, Ky. A small part of Wayne County, W. Va., and the south end of Lawrence County, Ohio, make up the remainder. The quadrangle takes its name from a small town, Kenova, lying at the confluence of Big Sandy and Ohio rivers.

The portions of Kentucky and Ohio in this locality are sometimes known as the "Hanging Rock" region, from an outcrop of massive sandstone at Hanging Rock on Ohio River, a few miles below the city of Ashland.

From a geographic as well as a physiographic point of view, this area is a part of the western Appalachian Plateau province. It lies along the western edge and just north of the center of the great coal field comprised within this province, which extends from north-central Alabama to the southern boundary of New York.

Previous field work.—This area was studied by the geologists of the Kentucky Geological Survey during the latter half of the past

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century. Most of the work on the coals and general geology in this particular area was done by Prof. A. R. Crandall. Mr. P. N. Moore examined more particularly the geology, distribution, and technology of the iron ores. Dr. I. C. White, director of the West Virginia Geological Survey, has measured sections in that part of the quadrangle which lies in Wayne County, W. Va., and the State Survey of Ohio has worked on the Ohio portion.

In addition to the work of these men special areas have been examined for private parties by geologists and mining engineers.

Literature.—The publications containing the most information on this area are the following:

Crandall, A. R., and Moore, P. N., Report on the eastern coal field: Geol. Survey Kentucky, vol. C, 1884, 77 pp.

The chapter on coals in this publication is also contained in Geol. Survey Kentucky, vol. 2, pt. 1, new ser., 1877, pp. 1–77; the discussion relating to the iron ores of Greenup, Boyd, and Carter counties, or the Kentucky division of the Hanging Rock iron district, is found in the same report, pt. 3, vol. 1, 1876, pp. 59–136.

Shaler, N. S., and Crandall, A. R., Report on the timber growth of Greenup, Carter, Boyd, and Lawrence counties: Kentucky Geol. Survey, new ser., vol. 1, pt. 1, 1876, pp. 1–58.

Survey of Big Sandy River, West Virginia and Kentucky, including Levisa and Tug Forks; House Doc. No. 326, 56th Cong., 1st sess., 1900, 62 pp.

Hoeing, J. B., Oil and gas: Kentucky Geol. Survey, Bull. No. 1, 1905, 233 pp.

White, I. C., Coal report: West Virginia Geol. Survey, vol. 2, 1903, 725 pp.

Stevenson, J. J., Lower Carboniferous of the Appalachian Basin: Bull. Geol. Soc. America, vol. 14, 1903, pp. 36 et seq., 80 et seq.

Stevenson, J. J., Carboniferous of the Appalachian Basin: Bull. Geol. Soc. America, vol. 15, 1904, pp. 92–114.

Ohio Geol. Survey, vol. 3, p. 1; vols. 5 and 7.

The reader will also get much information from the four volumes of reports of the first Kentucky Geological Survey, made by Dr. David Dale Owen in the years 1854 to 1860, inclusive. These early reports are somewhat discursive, and the information can most easily be found by reference to the indexes under the names of the various counties.

Present field work.—The field work on which this paper is based was done by W. C. Phalen in 1905, from the last of May to the first of November. George H. Ashley spent about two months in the field, visiting with the writer most of the critical areas and doing some independent mapping. David White also visited the field and spent somewhat less time making numerous careful and complete collections, which have furnished in part the basis for the separation of the formations chosen in geologic mapping. Numerous references to the work of Doctors Ashley and White will be found scattered through the text, and an expression of thanks is herewith extended to these geologists for courtesies both in the office and in the field.

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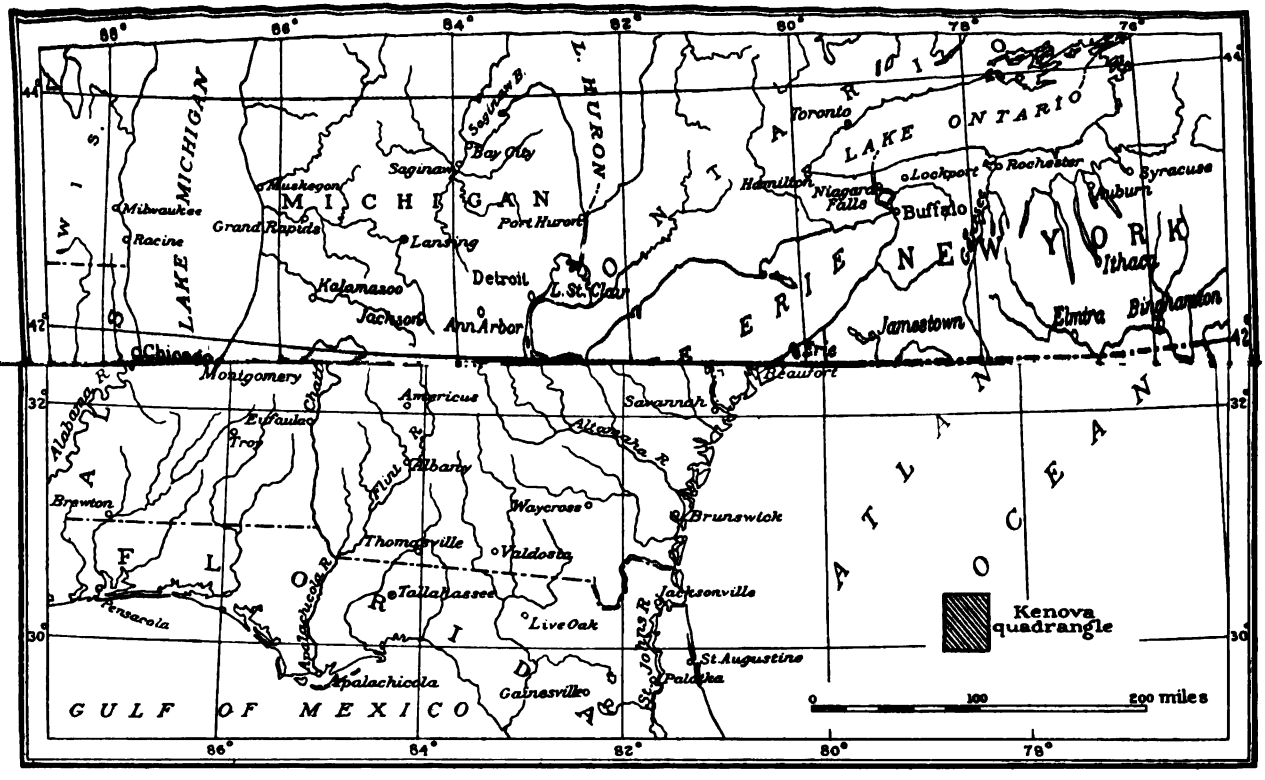

KEY MAP SHOWING LOCATION OF KENOVA QUADRANGLE WITH REFERENCE TO THE ENTIRE APPALACHIAN COAL FIELD.

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TOPOGRAPHY.

Relief.—The part of the Appalachian Plateau included in this region has been greatly dissected, until there is now scarcely any level land within the quadrangle, except the flood plains of the larger streams, like Ohio, Big Sandy, and Little Sandy rivers. This extensive erosion has resulted in sharp ridges, in many cases barely wide enough for wagon roads, and rather narrow valleys with small flood plains reaching well up to their heads. From the tops of the highest hills the remnants of the Appalachian Plateau may still be recognized in the even sky line (Pl. III, *A*). In a general way this ancient surface, or rather what remains of it, is highest at the south edge of the area, where the highest knobs reach an elevation of 1,200 feet. It slopes gradually northwest, and in the divide between the waters of Tygarts Creek and Little Sandy River only a few of the knobs rise above 1,000 feet. The lowest points in the area are those farthest downstream on Ohio and Little Sandy rivers and on Tygarts Creek. The flood plain of the Ohio ranges from about 530 feet above sea level where it leaves the quadrangle to about 560 feet where it enters it from the east. The flood plain of Big Sandy has an elevation of about 597 feet at the south edge of the quadrangle and 550 feet at the mouth of the stream, showing a gradient of about 1.1 feet per mile. This is slightly less than the gradient of Little Sandy. On Big Sandy the flood plain, though it may in places reach a mile in width, averages between one-half and three-quarters of a mile. The plain of Little Sandy from Grayson to Argillite has a greater average width, but in the upper portion of the river flood plains are wanting, the stream flowing through a gorge formed in the Sharon conglomerate.

The badly dissected character of the region has an important bearing on the exploitation of the natural resources. The railroads were confined during the early part of their history to the main river valleys and had to leave untouched for some time the more remote workable coal and clay beds; on the other hand, the flood plains, which are almost everywhere developed along the streams, are favorable to the construction of spur tracks that will materially lessen the haulage from mine breast to tipple.

Points of equal elevation are represented on the map by contour lines in buff, which are really the intersections of hypothetical plains with the surface of the country. These contour lines are placed 100 feet apart and, when carefully studied, enable the mind to grasp fairly well the general "lay of the land."

Drainage.—The drainage of this quadrangle is either directly or indirectly into Ohio River, which crosses its northeastern corner. The chief tributaries of Ohio River are Big and Little Sandy rivers

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and Twelvepole and Tygarts creeks, the last named flowing across the extreme northwestern corner. Twelvepole Creek, entering from the Huntington quadrangle on the east, flows about 10 miles in a circuitous course in West Virginia and empties into Ohio River at Kellogg. Practically all the smaller streams flow into Big and Little Sandy rivers. Of these streams Big Blaine, a tributary of Big Sandy with an estimated length of about 70 miles almost wholly included within this quadrangle, and East Fork of Little Sandy are the most important. The Big Sandy, which in conjunction with Ohio River is the main drainage course of the area, is formed by the confluence at Louisa of Levisa and Tug forks. After flowing northward for 27 miles, it empties into Ohio River at Catlettsburg. Levisa Fork is often called Big Sandy.

CULTURE.

Roads and farming.—Though from the farmer's point of view this area is rough, it is completely intersected by fairly good country roads, the construction of which is facilitated by the fairly soft character of the rocks. The roads of Boyd County are notably well kept.

Notwithstanding the comparatively rugged character of the country, it is under general cultivation. The flood plains of the streams, which are subject to periodical overflow, are on this account very fertile. Along the valleys of the larger streams some wheat is grown, but corn is the principal crop. In Carter County many of the hillsides are given to the cultivation of tobacco. These crops, with the usual garden truck, constitute the principal products of the soil. The timber resources of this area are of little or no importance. Most of the big timber was removed during the days of the old charcoal iron furnaces, which flourished during the seventies and early eighties.

Railroads.—Most of the railroads are confined to the larger stream valleys. The main line of the Chesapeake and Ohio Railway enters the area from Huntington, W. Va., and crosses Big Sandy River at Hampton, keeping along the south bank of Ohio River. The Big Sandy division of this line, formerly known as the Chatteroi Railroad, follows the west bank of Big Sandy River. During the summer of 1905 the old wooden railroad bridges were being replaced by substantial stone culverts, curves were being straightened, and general improvements were under way in preparation for an expected increase in the freight traffic from the Elkhorn and other coal areas near the headwaters of Levisa Fork. The Louisville and Lexington division of this railroad crosses the area diagonally from northeast to southwest, leaving the main line at Ashland. The coal mined at Straight Creek, Grant, Rush, Princess, and Winslow is carried by

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this line or by the Ashland Coal and Iron Railway, which is that portion of it between Rush and Ashland. The Norfolk and Western Railway has recently built a line down the eastern bank of Big Sandy connecting with its Twelvepole division and crossing Ohio River at Kenova. The new line is so much superior to the old in grade and general character that much of the coal from the headwaters of Tug Fork is now hauled over the new division. The Baltimore and Ohio Railroad has a terminus at Kenova. The Eastern Kentucky Railway, a short line constructed several years ago, has its southern terminus at Webbville, Lawrence County, and its northern terminus at Riverton, Greenup County, where it joins the Chesapeake and Ohio Railway. It carries staves, ties, etc., from the Blaine country and coal from its mines at Partloe, Boghead, and Hunnewell, as well as clay from the mines at Willard.

Locks and dams.—Big Sandy River has been under improvement by the United States Government since 1878. The plan of improvement adopted by Congress in March, 1899, contemplates carrying slack water as far as Pikeville on Levisa Fork, and to the mouth of Pond Creek on Tug Fork by the construction of 22 locks and dams. Within the limits of the Kenova quadrangle there have been built already three locks on Big Sandy below Louisa, one on Tug Fork at Saltpeter, and one on Levisa Fork at Chapman. By the aid of the dams the river will be navigable the whole year, instead of only about eight months, and the present commerce, chiefly in saw logs, cross-ties, staves, etc., will be largely augmented as a result of the cheaper water transportation. The development of the thinner coals within the Kenova area and in larger measure the thicker beds near the headwaters of the river will be aided. The navigable season of the smaller streams is so short that it will probably not aid materially in the development of the mineral wealth of this area. These streams are used chiefly in transporting logs and ties.

GENERAL GEOLOGY OF SURFACE ROCKS.

STRATIGRAPHY.

INTRODUCTORY STATEMENT.

All the rocks appearing at the surface within the limits of this quadrangle, with but a single exception, are of sedimentary origin and were laid down in or by water. They consist of sandstones, shales, limestones, coal beds, and iron-ore deposits, and have a total thickness of between 1,100 and 1,200 feet. All of these sedimentary rocks belong to the Carboniferous system, except the imperfectly consolidated gravels of the river terraces, which are of Pleistocene age, and the alluvium of the flood plains. The subdivision of the Carboniferous in the northwest portion of the Appalachian coal field,

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which was proposed by Henry D. Rogers in the reports of the First Geological Survey of Pennsylvania,[a] has been accepted and followed, at least in its main features, by all the geologists who have subsequently worked in the territory to which this subdivision applies. The coal-bearing rocks have been followed from Pennsylvania into Ohio, and then southward in Ohio to Jackson County, and from this county into Scioto and Gallia counties, and through them into and across Lawrence County to Ohio River. Thus the stratigraphy of the "Coal Measures" of western Pennsylvania is brought into the northeastern corner of the Kenova quadrangle. The Carboniferous system, as developed in this quadrangle, consists of parts of the Pennsylvania and Mississippian series. The former contains the workable coals of this area. The rocks will be described in descending order, beginning with the youngest.

SEDIMENTARY ROCKS.

QUATERNARY SYSTEM.

Recent deposits.—The alluvium of the streams of this area is the youngest bedded deposit and has considerable commercial importance. It makes up the flood plains of both the large and the small streams, extending well up to their heads. The larger streams, like Ohio, Big Sandy and Little Sandy rivers, have deposits of this material fully 50 feet thick. Along Ohio River the width of this flood-plain deposit ranges from three-fourths of a mile to a mile, but on Big Sandy and Little Sandy rivers these deposits are not quite so wide. The material is being constantly cut out and redeposited by variations in the currents at each period of high water.. The mode of utilization of these flood-plain deposits will be indicated in connection with the description of the clays (p. 120).

Pleistocene deposits.—None of this region lies within the glacial boundary, but there are deposits within the area which are considered of Pleistocene age. Just back of the city of Ashland is a district known as the Flatwoods, where the hills are flat and do not rise to an altitude of over 700 feet. These flat lands are covered with deposits of sand, gravel, quartz, and chert bowlders, some of which are 12 inches in diameter. These represent residual material from the remains of older crystalline rocks of the Blue Ridge to the east. This deposit may be traced fairly distinctly up Big Sandy River to the south of Louisa, maintaining its general elevation of about 150 feet above the present flood plain of the stream. These gravel deposits may, and do in places, represent the valleys of streams which long ago ceased to flow through them. The proof of this statement lies in the rounded character of the bowlders and in

[a] Vol. 2, pt. 1, 1858, p. 16 et seq.

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A. OHIO TOPOGRAPHY, SHOWING LEVEL SKY LINE.

B. MAHONING SANDSTONE, LITTLE ICE CREEK, LAWRENCE COUNTY, OHIO.

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certain topographic features usually associated with streams. Among the more conspicuous features of the remnants of these old, high-level valleys are their well-graded walls and the maturity indicated by their flat-bottomed floors. This floor in the Flatwoods area is nearly a mile wide. The old drainage channel represented by the Flatwoods is regarded by W. G. Tight[a] as a continuation of the preglacial Teays River.

Similar deposits have been found on the Little Sandy at elevations closely approximating those of the Big Sandy, and though the correlation of the two deposits has not been attempted, it is probable that the benches and their associated gravels on Little Sandy, when traced up Ohio River, will merge into those on Big Sandy. Silt associated with quartz pebbles has been discovered at lower elevations on Little Sandy, indicating a quiescent condition of the water with periods of deposition while these ancient streams were probably subsiding. Since these deposits, as developed in the Kenova quadrangle, have no economic significance, they will not be considered further.

CARBONIFEROUS SYSTEM.

PENNSYLVANIAN SERIES.

Monongahela formation.—The Monongahela in Pennsylvania was first termed the "Upper Productive Measures," since it marks an epoch in which several workable beds of coal were deposited. The base of the formation is marked by the Pittsburg coal. In accordance with Dr. I. C. White's correlation, the coal at the top of the hills east of Lett, near the mouth of Gragston Creek, West Virginia, is accepted for the time being as the Pittsburg coal and as marking the base of the Monongahela formation.[b] The area underlain by the coal does not exceed a few acres, and the formation is represented by 100 feet of shales with a massive sandstone at its base. No important coals are found in it except the Pittsburg bed.

Conemaugh formation.—The Conemaugh includes the rocks lying below the Pittsburg coal and above the Upper Freeport coal. What is regarded as the Upper Freeport coal with its overlying massive Mahoning sandstone is well exposed below Louisa in the vicinity of Zelda, and on Blaine Creek near Fallsburg. Above the sandstone which forms the roof of the Upper Freeport coal, and which varies in thickness from 20 to 30 or more feet, the rocks are in marked contrast with the rocks below, both in character and in the number and importance of the coal beds.[c] The massive sandstone is probably the

[a] Prof. Paper U. S. Geol. Survey No. 13, 1903. For a very complete description of Teays River to the east of this area see M. R. Campbell, Description of Huntington quadrangle; Geologic Atlas U. S., folio 69, U. S. Geol. Survey, 1900, pp. 2–3.

[b] West Virginia Geol. Survey, vol. 2, 1903, pp. 191–192. See also pp. 16–17 of this bulletin.

[c] Kentucky Geol. Survey, vol. C, 1884, p. 60.

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same as that which overlies the Waterloo, Bayleys Run, No. 7, or Upper Freeport coal of the Ohio geologists, and which makes such a striking appearance along the banks of Big Sandy River near its mouth. The coal at its base in Lawrence County, Ohio, is regarded by the geologists of that State as higher than the Hatcher or No. 8 coal of the Kentucky reports.[a]

The position of the coal under consideration, which north of Louisa is immediately below a massive sandstone, the Mahoning of Owen, is strong evidence that it corresponds more probably with the coal above the Hatcher bed. Crandall, however, in his report on the geology of Greenup, Carter, and Boyd counties, explicitly states that coal No. 8 of the Kentucky survey is the first coal below the Mahoning sandstone of Owen, and follows the statement with the words that this coal is commonly known as the Hatcher seam.[b] In another place[c] he states that above the shales containing coals Nos. 7 and 8 occurs a coarse ferruginous sandstone, the Mahoning of Owen and Lesquereux. In this sandstone and its overlying rocks are found coals Nos. 9, 10, 11, 12, etc. However, J. J. Stevenson, in his description of the Allegheny formation in Kentucky,[d] interprets Crandall's generalized section of Greenup, Boyd, and Carter counties as placing coal bed No. 9 below the Mahoning sandstone.

In view of the evidence outlined above, the coal which has been opened below the massive sandstone exposed near Zelda and Fallsburg is regarded as the Upper Freeport and as the first bed above the Hatcher coal or No. 8 of the Kentucky reports. Normally, therefore, it would be No. 9 of the Kentucky series, and instead of coming within the Mahoning sandstone would occur just below it, as in Pennsylvania.

The minimum thickness of the Conemaugh formation is between 300 and 400 feet. It is almost entirely exposed only in a small area near the center of the basin in the hills east of Lett, W. Va. This may be due to a possible local thinning of the formation, for at other points near the center of the basin, west of Big Sandy River, where the hills rise as high, nothing is apparently known of the existence of the Pittsburg coal. If the thickness of the Conemaugh formation, 300 to 400 feet, obtained under the assumption that the coal in the hilltops near the mouth of Gragston Creek, West Virginia, is the Pittsburg bed, is compared with the thickness of that formation at Charleston and Huntington given by I. C. White, some question may be raised as to the correctness of the identification of the Pittsburg bed. White makes the Conemaugh 800 feet thick at Charleston and

[a] See section by E. McMillan, Ohio Geol. Survey, vol. 5, 1884, p. 122.
[b] Kentucky Geol. Survey, vol. C, 1884, p. 24.
[c] Idem, pp. 9, 10.
[d] Bull. Geol. Soc. America, vol. 17, 1906, p. 128.

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660 feet at Huntington. However, the correctness of his identification of the Upper Freeport coal at Charleston has been questioned, both David White and J. J. Stevenson placing the Upper Freeport well above the black flint, thus reducing the thickness of the Conemaugh formation to a little over 600 feet. G. H. Ashley has been inclined to reduce it to 530 feet or less. The section of the Conemaugh formation obtained by the Ohio geologists in Lawrence County, Ohio, is only 420 feet thick, suggesting a westward thinning of the formation, which is in full accordance with the westward thinning known to take place in going from Pennsylvania across the panhandle of West Virginia into Ohio. If the coal in the Kenova quadrangle is the Pittsburg bed, the thickness of the Conemaugh is much less than it is to the northeast at Huntington and slightly less than the Ohio geologists make it.

The rocks of the Conemaugh are mainly red or greenish shales, with beds of limestone and iron ore and in some localities important beds of sandstone. The fact that it contains no workable beds of coal, together with the sharply defined character of its rocks as contrasted with those of the formations above and below, serve in part as a basis for making it a separate formation. The members of the formation in this area are generally irregular in their development, and are on this account poor guides in unraveling the stratigraphy. The basal member, however, which is the Mahoning sandstone, is very persistent and hence a valuable guide in tracing this formation. (See Pl. III, *B*.) Above this sandstone at variable intervals occurs a rather persistent limestone, one of the Cambridge limestones, which is usually capped by a cliff-making sandstone. These two massive sandstone members occurring near the base of the Conemaugh serve to clearly demark it in most localities from the underlying rocks, the more so because the succeeding higher rocks are usually red shale. In some parts of the quadrangle, notably near the mouth of Big Sandy River, the basal sandstone is unusually thick and massive, attaining near Kenova a thickness of 70 feet, and is continuous, with but a few irregular intercalations of shale, east to Ceredo, south of which it becomes even more massive and attains a thickness of 100 feet. Above this sandstone there is usually a small coal, which may be the Brush Creek coal of Pennsylvania. This is an unimportant bed, though it has been worked in the hills opposite Louisa. It will probably not be of any great commercial importance in the near future. The Cambridge limestone overlying the Brush Creek coal is a very persistent member and is a most valuable guide in tracing the rocks of the Conemaugh. In many places it consists of two members, an upper and a lower, as shown by the section obtained near the bed of Whites Creek, about 1 mile west of Potomac (p. 131).

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In the western part of the quadrangle, near Willard, this limestone usually occurs as a single layer. At Willard it is found near the hilltops 180 feet above coal No. 7, but the interval above this coal is in some places slightly less than that. This limestone has a very characteristic appearance, and, owing to the fact that it is highly siliceous, it withstands weathering, and can usually be found at its proper horizon. Almost directly above it occurs a small bed of coal, locally workable. Overlying this coal at a varying interval is a massive sandstone. The distance between the base of this sandstone and the limestone ranges from 10 to 40 feet, but averages about 35 feet. This sandstone is rarely more than 25 to 30 feet thick, but is usually massive and coarse grained, and makes prominent outcrops. Capping this sandstone is a mass of red shale, near the base of which occurs a small bed of coal. The remainder of the Conemaugh is prevailingly red, and for the most part the rocks are shales or shaly sandstones with a few bands of massive sandstone. (See Pl. III, *B*.) The formation contains practically no workable coal.

Allegheny formation.—The Allegheny formation underlies the Conemaugh and is about 180 feet thick in the northern part of the quadrangle, but in places it varies considerably from this thickness, as in the southern part of the area, where the thickening of the Homewood sandstone seems to have interfered with the normal development of the Allegheny. The top of this formation is the top of the Zelda coal, which is believed to correspond to the first bed above the true Hatcher coal of Ohio, and hence to be the Upper Freeport coal of Ohio and normally No. 9 of the Kentucky series. The base of the formation is demarked from the underlying rocks both on paleontologic and lithologic grounds. It is the base of coal No. 5 of the Kentucky series, which according to Stevenson [a] corresponds to the Brookville coal of Pennsylvania. This coal lies practically at the top of a massive sandstone in the Kenova quadrangle, which is regarded as the equivalent of the Homewood sandstone at the top of the next lower (Pottsville) formation. In the western part of the quadrangle, though all the more constant members of the Allegheny are present, the formation seems to be thinner than in the region around Ohio River and to show considerable variation. On one side of the hill west of Willard it is about 130 feet thick, but on the other side it is less than 100 feet. It should be noted that in this district the Homewood sandstone thickens to 100 feet, and in general it may be said that throughout the area the Allegheny formation tends to become thin as the underlying Homewood sandstone thickens. This formation was known in Pennsylvania as the "Lower Productive Measures," from the fact that it is the lower of the two groups of rocks containing valuable coals. It also contains a valuable clay deposit in this part of

[a] Bull. Geol. Soc. America, vol. 17, 1906, p. 128.

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Kentucky. In addition it contains beds of sandstone, shale, iron ore, and limestone. Unlike the formation on which it rests, it is, as a rule, not decidedly sandy, and the character of its fossil plants is so distinct from that of the plants in the Pottsville as to warrant its separation as an independent formation.

The number of coals present in the Allegheny formation is usually not more than six, and in many places not more than four. The lowest coal, No. 5 of the Kentucky Survey, lies directly on the Homewood sandstone. It is locally of workable thickness.

An important member in this formation has been called the "Ferriferous" limestone by Andrews in the reports of the Ohio Geological Survey, and the "Hanging Rock" limestone by Orton.[a] It is the equivalent of the Vanport ("Ferriferous") limestone of western Pennsylvania, and that name will be used in this report.

Its relationships in the Kenova quadrangle may easily be made out at Coalgrove, opposite Ashland. (See section on pages 30–31.)

It usually lies from 10 to 20 feet above the top of the Homewood sandstone, and is found at its top in many places where coal No. 5 is absent. It is generally associated with an important clay bed, and on this account has an economic interest. This clay ranges in thickness from 4 to 6 feet. The next higher economic member in this formation is the No. 6 coal of the Kentucky section, known in the region about Ashland as the "Limestone coal" and in Ohio as the "Newcastle coal." It is commonly found 20 feet above the Vanport ("Hanging Rock") limestone.

The next higher coal is the Coalton, or the No. 7 of the Kentucky Geological Survey, or the No. 6 or Sheridan coal of Ohio. This is the celebrated Nelsonville coal of the Hocking Valley. It is the most important bed in this area at present and is found from 25 to 45 feet above coal No. 6 and from 40 to 50 feet below coal No. 8, the next higher bed in the formation. This coal No. 8 is workable in parts of the quadrangle, but is as yet comparatively unimportant. From 40 to 50 feet higher in the scale is coal No. 9, which, like the coal below it, is generally a thin bed and only locally workable.

Besides the coals and fire clays of economic importance in this formation, various beds of iron ore occur. These formerly had considerable importance, but at present have little or no value, as the cheaper ores of Lake Superior and Alabama have entirely replaced them in the market. The general sections (Pl. IV and fig. 20) show the beds of economic interest and the intervals between them.

Pottsville formation.—The Pottsville formation is the lowest in the Pennsylvanian series. Its base is the top of the Mississippian series, on which it rests unconformably, and it comprises all the rocks

[a] Ohio Geol. Survey, vol. 3, pt. 1, 1878, pp. 885 et seq., 892 et seq.

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to the top of the Homewood sandstone. This formation is separated from that lying below and from that above on both lithologic and fossil evidence. The entire formation is exposed in the northwestern part of the quadrangle, where it has a thickness of between 350 and 400 feet. In the southeastern part of the area it has a thickness of at least 600 feet, and along the southern edge it must be fully as thick. General sections showing the character of the rocks of this formation, as exposed at different points of the area, are given in Pl. IV. The rocks of this formation are decidedly sandy, but contain occasional beds of shale, iron ore, limestone, and coal. Owing to its thickening in the southeastern part of the area and the introduction of coal beds not represented in the section in the western part of the field, the lowest coals in the area are believed to appear in the section along Levisa Fork near Gallup. There are three or four of these beds, and the thickest of them is not over 2 feet at any point. The higher coals in this formation are all locally workable and have been numbered by Prof. A. R. Crandall (Pl. IV). There are usually four fairly thick coal beds in this formation, but at some points this number may be increased to five and even six. Detailed descriptions of these coals, together with the intervals which separate them, are given under the headings of the various districts.

The Pottsville formation also contains some very valuable beds of fire clay. Most noteworthy of all is the bed occurring only a few feet above the top of the Maxville limestone. This is the celebrated Sciotoville fire clay of Ohio. Though it outcrops over a very small area in this particular quadrangle, it has considerable economic importance to the west, and it is being mined at present on a large scale in the vicinity of Olive Hill. Other beds of fire clay in this formation are locally workable, notably the bed associated with coal No. 4, which has been worked in the eastern part of Ashland and on Catletts Creek. Nearly one-half of the entire surface of this quadrangle is covered by rocks belonging to the Pottsville.

MISSISSIPPIAN SERIES.

The Mississippian series is represented by a massive limestone, called in the Kentucky reports "Sub-Carboniferous limestone," and in those of Ohio the Maxville limestone. About 100 feet of the Waverly group is also present. The outcrops of the limestone are confined to the western part of the area and are limited in extent. West of Tygarts Creek, in Greenup County, this rock is present in the hills. Here it does not exceed a thickness of 25 feet, being underlain by 100 feet of sandstone and shale belonging to the Waverly. A small outcrop of limestone is found at the bend in Everman Creek, Carter County, just above the mouth of Wolfpen Branch, and again farther up the creek, just at the edge of the quadrangle. The lime-

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stone in this part of the field does not exceed 15 or 20 feet in thickness. It is usually overlain by a thin band of iron ore. This limestone is encountered in all the deeper borings for oil, in both the eastern and western parts of the quadrangle, and reaches in places a thickness of several hundred feet. The total thickness of the Mississippian rocks outcropping in the western part of the area does not exceed 150 feet.

IGNEOUS ROCKS.

Occurrence.—Igneous rocks in this quadrangle were noted by Professor Crandall many years ago. They are found in the hills on each side of Ison Creek west of Stephens, Elliott County, and about 8 miles southwest of Willard. The region was visited by J. S. Diller, of the United States Geological Survey, in 1884, and as a result of this trip a very detailed account of the occurrence and petrography of these rocks was published.[a] The rock is peridotite, and owing to this fact is of more than usual interest, first, because it bears a resemblance to the peridotite of South Africa, the mother rock of the diamond, in the Kimberley district; and second, owing to the relative scarcity of this type of igneous rock and to a possible relationship to the mica peridotite of western Kentucky.[b] In another publication Mr. Diller has applied the name of kimberlite to this rock from its resemblance to the South African rock.[c]

Extent.—The area covered by the rock is very small, not more than a few acres. The outcrops of the solid ledge are not numerous, but their original extent is not difficult to trace, owing to the characteristic minerals resulting from weathering. There is no apparent reason why the various isolated masses should not be considered parts of a single intrusion, as all appear identical in mineral composition.

Character of rock.—The groundmass of this rock is compact, grayish black in color, and porphyritic. It is plentifully specked with phenocrysts of olivine, which appear to be very fresh and unaltered and give a grayish tinge to the rock. Garnet (pyrope) and titanic iron ore (ilmenite) are also easily detected and in the field were found to be of great assistance in tracing the boundaries of the decayed ledges. Sections of biotite are not uncommon. Besides these constituents, which are readily detected in the hand specimens, the chief remaining minerals are enstatite and a small amount of apatite. In places the olivine has been altered to serpentine, which may be readily seen in hand specimens, and which in thin section is associated with magnetite and some carbonate, presumably dolomite resulting from the alteration of the olivine. This rock has been so thoroughly described by Diller, and its peculiar characteristics are

[a] Bull. U. S. Geol. Survey No. 38, 1887.
[b] Williams, G. H., Am. Jour. Sci., 3d ser., vol. 34, Aug., 1887, p. 137.
[c] Bull. U. S. Geol. Survey No. 150, 1898, pp. 290–294.

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so well pointed out in his publication, that it will not be further considered here.

Age and relationships.—The sedimentary rocks through which the igneous rock has forced its way are traceable practically up to the contact and strangely enough do not appear to have been even flexed upward along this zone. Though the igneous rock has broken off masses of shale, which are now found embedded in it, this is surprisingly fresh and unaltered, like the ordinary black shale of the Pennsylvanian series. Only in a few cases are metamorphic effects markedly visible. In some of the baked shale secondary mica was seen in considerable quantity. The color of the shale had been somewhat reddened and the sandstone and limestone fragments, which were inclosed by the igneous rock, had been baked and the latter converted to quicklime.

The sedimentary rocks in which the bulk of the igneous rock is found belong to the Pottsville formation, but as some of the igneous rock is found in the Allegheny, the intrusion is Allegheny or post-Allegheny in age. It was forced into the carbonaceous shale and coal beds found in this formation, and, owing to the fact that the Kimberley diamonds occur in peridotite penetrating carbonaceous shale, more than ordinary interest attaches to the Elliott County occurrence of peridotite. This interest has led to the prospecting of streams in the neighborhood, and also to the sinking of a shaft 70 feet deep, which at the time of the writer's visit (October, 1905) was filled with débris. During the spring of 1906 it was reported that another prospect shaft was being sunk. As to the presence of diamonds the writer has no authentic information.

STRUCTURE.

MODE OF REPRESENTING STRUCTURE.

The inclination of the beds to a horizontal plane, or the dip of the beds, as it is commonly called, is measured in the field by means of a clinometer when the inclination is great enough to be susceptible to this method. In but few localities, however, in the Kenova quadrangle are the dips sufficient to allow this mode of measurement. Where this method is not applicable continuous road sections are run and the beds are correlated from hillside to hillside. When the elevation above mean sea level of a given sandstone, coal, or limestone on one hill and its elevation a mile or so away have been found, the rise or fall of this particular bed in feet per mile is at once obtained. By connecting points of equal elevation on any selected bed the contour lines for that bed are drawn. On the map, Pl. I, the contour interval is 50 feet and all points having altitudes

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that are multiples of 50 were connected by black lines. For instance, in drawing the 600-foot contour line those points in the area where the datum selected (the top of the Homewood sandstone) reached this elevation were connected, and likewise for the other contour lines.

The top of the Homewood sandstone was selected in this area, on account of the ease with which this bed may be followed, owing to its persistence and relations to other well-known horizons. Where it failed to appear above drainage, its distance below other known beds was used, assuming, of course, that the distance was constant within the limited area where this means was employed. Conversely, when the dips were such as to carry the top of the Homewood above the hilltops its distance above known beds was applied. However, great precision was not obtainable, as such intervals are subject to variation all over the region, and especially in the areas covered by the formations above the Homewood. Furthermore the elevations were obtained by means of aneroid barometers, which are liable to sudden variations and have to be constantly checked against spirit-level elevations. In spite of these sources of error, it has been thought advisable to draw structure contour lines. These show the generalized surface formed by the top of the Homewood sandstone, and, less precisely, the lay of the overlying and underlying beds. The limit of error may generally be considered a contour interval, but where the beds vary in thickness as they do in this area it may be more. This mode of presentation, in addition to showing the structure of the beds, enables us to estimate the elevation of the top of the Homewood sandstone when it is below drainage. For instance, near Zelda the 400-foot contour line was drawn. The elevation of Zelda is 580 feet above mean sea level; therefore, the top of the Homewood sandstone should be at a depth of 180 feet. The distances of the various coal beds above or below the top of this sandstone being known, their depth below the surface may in turn be estimated at this point.

DETAILED DESCRIPTION OF STRUCTURE.

This quadrangle lies at the southwest end of the great trough formed by the coal-bearing rocks of the Appalachian field. The axis of the trough extends southwest from near Pittsburg, Pa., and the trough reaches its maximum development near central West Virginia. From this point southwestward the axis slowly rises, crossing Ohio River a little east of the quadrangle and reaching Big Sandy River from 8 to 10 miles above its confluence with the Ohio. The axial line follows Big Sandy River southward for 2 miles and gradually curves to the west, pitching upward along a line practically coincident with the boundary between Carter County and Elliott

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and Lawrence counties. The beds south of the axial line dip north and northwest, and those on the northern side dip southeast. The dips over most of the area are not very steep. In the northern two-thirds of the quadrangle the dips, with a few exceptions, do not average as high as 50 feet per mile. Near Catlettsburg the upper part of the Pottsville formation is exposed at railroad level, but across Big Sandy River the lowest rocks exposed in the cliffs along the Norfolk and Western Railway are the lower sandstone members of the Conemaugh formation; thus a dip of more than 50 feet per mile is involved between these points. Near Willard and southwest of this town in Carter County the dips are above the average, being close to 100 feet per mile. The steepest dips are confined to the southern third of the area. This belt of sharp dips is about 6 miles broad south of Louisa, but it narrows westward until at Blaine it is not more than a mile in width. West of this town the beds curve gently northwestward around the head of the basin. The dips in the ridge south of Louisa are fully 100 feet per mile. Near Adams and on Right Fork of Blaine Creek the rocks in places dip 300 feet per mile. The steepest dips in the area are near the mouth of Hood Creek in the eastern part of the town of Blaine. At the bridge over Hood creek the beds are inclined 11 degrees, and near this point two small faults were discovered by Mr. Ashley, but their throws are probably not great enough to materially affect the structure contours.

A few minor flexures are involved in the main syncline. In the region near Irad and Osie, Lawrence County, the Homewood sandstone thickens toward the west very rapidly, causing a slight arch in the overlying beds, but west of this district the sandstone is somewhat thinner and causes a slight depression. West of Cherokee Creek, approaching Elliott County, the structure seems to be rather irregular. This may be more apparent than real, and the irregularity in the contours may be due to the fact that they are based on but few outcrops and that the underlying sandstones, which might serve as a guide, thicken and cut out the coal beds. The flattening of the beds to the west is due to the dying out of the Appalachian folds as the Cincinnati arch is approached. West of this quadrangle the beds gradually rise to the apex of this arch, and this gradual rise is indicated in the contours west of Little Sandy River.

MINERAL RESOURCES.

GENERAL STATEMENT.

In an area of sedimentary rocks, like the Kenova quadrangle, in which the chief deposits are sandy or clayey, it is useless to attempt to find such metals as gold, silver, and lead in paying quantities.

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Small amounts of lead, zinc, and iron sulphides do occur in the clay-limestone concretions in the shales of the Carboniferous system, but the amount of such material is so small as to be entirely negligible, and time devoted to the search for the precious and base metals will be fruitlessly spent. On the other hand, the coal and fire-clay beds may repay more careful prospecting than has heretofore been given them, and perhaps to a less extent this is also true of the alluvium of the stream beds, the shale, the limestone, and the sandstone beds.

COAL.

Workable beds of coal are scattered through nearly the entire geologic column, as developed in this area, up to and including the celebrated Pittsburg coal at the base of the Monongahela formation. The names, positions, and relationships of these coals are given in the general columnar sections (Pl. IV) and also in the local sections.

These coal beds vary somewhat in character but include most varieties of the bituminous class. The bulk belong to the harder, bituminous variety, and in many places have a splinty aspect. The coals, as a rule, break into rather thin slabs along charcoal layers, and hence may be classed as semiblock coals. As a rule they are unsuitable for coking, but after washing some of them give fair satisfaction. Coal No. 6, or the Winslow coal, which has been mined for several years at Winslow, has been washed and coked by the Ashland Iron and Mining Company for use in the company's furnaces at Ashland, and has always proved fairly satisfactory when mixed with a small amount of some standard coke or when coked with a small amount of some standard coking coal. All the coals give excellent results when used for ordinary steam and domestic purposes. Nearly all bear well transportation and stocking. Coal No. 7, or the Coalton coal, which ranks with and is stratigraphically equivalent to the famous Nelsonville coal of Ohio, has been and is still used by the Ashland Iron and Mining Company in its blast furnaces at Ashland.

Ordinary bituminous coal is frequently associated with the splinty variety in most of the coal beds. It is finely interlaminated with a dull splint in many of the benches, and in other places it forms complete benches by itself. This is sometimes the case with the Winslow coal, the bottom bench of which is usually of the soft bituminous variety and contrasts with the harder splinty type of the two upper benches. Certain beds in restricted areas contain benches of cannel coal, for example, the coals now being worked by the Kentucky Cannel Coal Company at Boghead and Hunnewell. Sections obtained at Boghead show the character of these two coals at this point.

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Relations of coal and other important beds in the Kenova quad-

System.	Series.	Formation.	Names used in this report.
Carboniferous.	Pennsylvanian.	Monongahela.	Pittsburg sandstone
			Pittsburg coal
		Conemaugh.	Ames limestone
			Cambridge limestone
			Brush Creek coal
			Mahoning sandstone
		Allegheny.	Zelda coal
			Hatcher coal
			Red kidney ore
			Coalton coal
			Yellow kidney ore
			Winslow coal
			Iron ore.
			Flint and plastic clay
			Vanport ("Ferriferous") limestone
			Flint and plastic clay
			Cat Creek coal
		Pottsville.	Homewood sandstone
			Lick Creek, Catletts Creek, or Upper Stinson coal
			Iron ore
			Torchlight or Lower Stinson coal
			Danleyton coal
			"Little Cannel" or Barrett Creek coal
			Massive sandstone
			Sharon coal
			Sharon conglomerate
			Salt sand
			Sciotoville fire clay
	Mississippian.		Iron ore
			Maxville limestone
			Waverly group
			Big Injun sand
			Sunbury shale
			Berea sandstone
			Bedford shale
Devonian.			Ragland sand
			Ohio shale

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rangle, with names used in Pennsylvania, Ohio, and Kentucky.

Pennsylvania names.	Ohio names.	Kentucky names.
Pittsburg sandstone		
Pittsburg coal	Pittsburg coal	
Ames limestone	Ames limestone	
Pine Creek or Coleman limestone.	Upper Cambridge limestone	Upper Cambridge limestone.
Brush Creek limestone	Lower Cambridge limestone	Lower Cambridge limestone.
Brush Creek coal		
Mahoning sandstone	Mahoning sandstone	Mahoning sandstone.
Upper Freeport coal	Bayleys Run, Waterloo, or No. 7 coal.	No. 9 coal.
Lower Freeport coal	Hatcher or No. 6 A coal	No. 8 coal.
Middle Kittanning coal	Sheridan, Nelsonville, Straitsville, Lower Waterloo, Ashland, Mineral City, or No. 6 coal.	No. 7 coal.
Lower Kittanning coal	Newcastle or No. 5 coal	No. 6, Keyes Creek, River Hill, or Limestone coal.
Vanport or Ferriferous limestone.	Hanging Rock or Ferriferous limestone.	
Brookville coal	No. 4 coal	No. 5 coal.
Homewood sandstone		
Upper Mercer coal	No. 3 A coal	No. 4 coal.
Lower Mercer coal	Lower Mercer coal	No. 3, McHenry's, or Torchlight coal.
Quakertown coal	Quakertown coal	No. 2 coal.
		No. 1 or Barrett Creek coal.[a]
Sharon coal	Jackson Shaft coal	
Sharon conglomerate	Sharon conglomerate	
		Maxton sand.
	Sciotoville or Logan fire clay	
Greenbrier limestone or Big lime.	Maxville limestone	Subcarboniferous limestone.
	Waverly group	Waverly series.
Burgoon sandstone or Big Injun sand.	Logan formation (?), Blackhand formation, or Cuyahoga formation.	Big Injun sand.
	Sunbury shale	
	Berea sandstone	
	Bedford shale	
		Ragland sand.
	Ohio shale	Ohio or Chattanooga shale.

[a] See p. 93.

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Section of No. 4 coal bed at Boghead.

Shale roof.	Inches.
Coal, bituminous	7½
Bone	½
Coal, bituminous	11
Fire clay	7½
Bone	6½
Coal, cannel	9
	42½

Section of No. 3 coal bed at Boghead.

Shale roof.	Inches.
Coal, bituminous	5
Bone	2
Coal, cannel	15
Fire clay	15
Coal, bituminous	14½
	51½

It is reported that the cannel layers are erratic in their occurrence, being as liable in No. 3 bed to occur in the top as in the middle bench. In the hill southeast of Hunnewell the middle bench is cannel coal. In Elliott County, near the western edge of the quadrangle, in the hills west of Stephens and north of Fielden, there is an important cannel bed well up in the top of the hill. Old openings were observed by the writer, but there was no opportunity to measure the coal. G. H. Ashley found the cannel layer 4 feet thick in places in the hills south of Critches Creek. This coal bed lies about 50 to 60 feet above the top of the Homewood sandstone and is tentatively correlated with the Winslow or No. 6 coal of the country to the east. On Hilton Branch, southwest of Willard, a rather thick bed of cannel has been worked in a small way. The seam was opened on the land of William Corey and Elijah Sturgill. At the opening on Mr. Corey's property the coal measured 29 inches of cannel with more lying below unseen on account of the water which nearly filled the opening. Mr. Sturgill, jr., reports 36 inches of cannel overlain by 8 inches of bituminous coal, capped by a sandstone roof. The Brush Creek coal of Lawrence County also contains a cannel layer. Besides these beds of cannel coal there are others containing sufficient volatile hydrocarbons to class them with the cannel coals. This is the case with certain layers in the Torchlight or No. 3 coal of Levisa Fork, Lawrence County, while the "Little Cannel" bed lying 140 feet below No. 3 at Torchlight contains a band whose analysis shows 55 per cent of volatile matter. Pl. IV and the table on pages 26–27 show the relations of the various coals and their equivalents in Pennsylvania, Ohio, and Kentucky.

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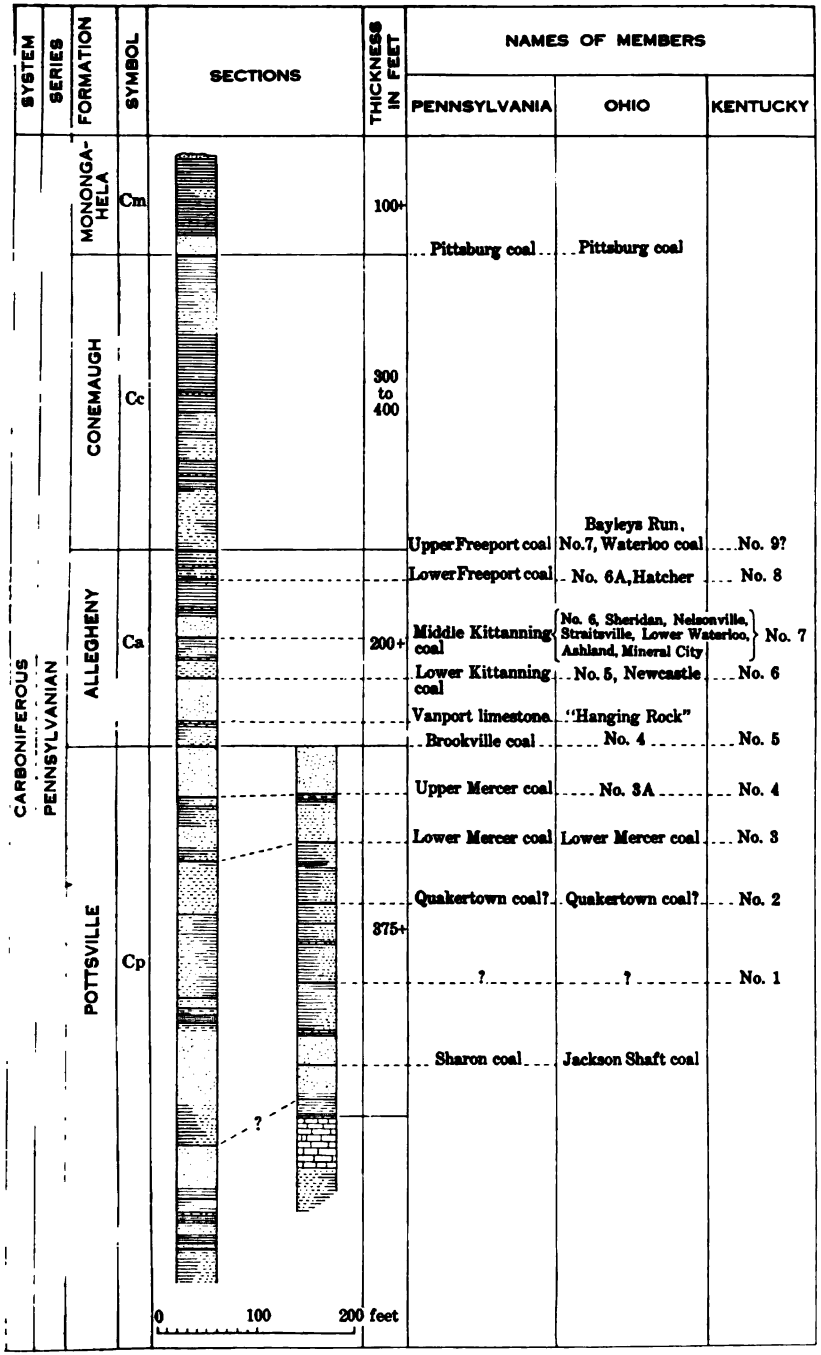

GENERAL SECTIONS SHOWING RELATION BETWEEN THE COALS IN THE KENOVA QUADRANGLE AND THEIR EQUIVALENTS IN PENNSYLVANIA, OHIO, AND KENTUCKY.

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CLAY.

The clays of the Kenova quadrangle are all sedimentary in origin and have reached their present position through the agency of water. They may be divided as regards both age and adaptability into two classes. First, the bedded clays, and, second, the recent unconsolidated silts or clays of the stream valleys. Of the former class two beds are prominent.

The higher of the bedded clays is that occurring near the horizon of the Vanport ("Hanging Rock") limestone, about 10 to 40 feet above the top of the Homewood sandstone. Though not so important as the lower fire clay at Olive Hill (the Sciotoville clay of Ohio) in the northeastern part of Kentucky, yet, when taken as a whole, it is of far greater importance in the Kenova quadrangle. On the economic map the red line, except along Tygarts and Everman creeks, Carter County, may be taken as the outcrop of the Vanport ("Hanging Rock") limestone with its associated clay. Detailed descriptions of the characteristics of this clay, as noted at different localities, are given on pages 113–117.

The lower of the two important clays occurs a few feet above the Maxville limestone and is one of the most important fire clays of northeastern Kentucky and southern Ohio. This is the celebrated Sciotoville clay of the Ohio Geological Survey reports, less widely known as the Logan clay. It has been extensively mined at Sciotoville and in the region around Portsmouth, Ohio, and is also mined on a large scale at Olive Hill, Ky., and in the valley of Tygarts Creek, which cuts across the northwestern corner of this quadrangle. In this area the fire clay appears at a few points near the western boundary and these occurrences are described in detail on page 118.

The recent clays of the flood plains of the rivers and small streams are widespread, even the smallest streams having in places extensive deposits. Those which are worked at present are confined to the Ohio Valley, where there is a local market, cheap coal, and convenient transportation facilities. This flood-plain clay is suitable chiefly for ordinary building brick, tile, shingles, etc.

Other important clays are found, but they are not so persistent as those noted above. Among those of less importance is the fire clay associated with coal No. 4 at Ashland and Catlettsburg and in the hills northwest of Willard, near the headwaters of Johns Creek.

Besides clays proper there is in the Carboniferous rocks over the entire quadrangle an abundance of raw material, such as ganister (siliceous clay) and numerous shale beds, which thus far has not even been prospected. This no doubt would make brick of fair grade.

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MISCELLANEOUS ECONOMIC PRODUCTS.

The less important resources of this area are limestone and iron ore, sandstone, oil, gas, glass sand, and salt. These commodities will be considered in detail in a subsequent part of this bulletin.

DESCRIPTION OF COAL RESOURCES BY DISTRICTS.

For convenience in reference and from a commercial rather than a scientific point of view the coal resources of this area are described by districts whose boundaries have been chosen so that each district may coincide as closely as possible with the country naturally tributary to a certain railway line or other highway of communication. These districts are as follows:

1. Ohio district.
2. Big Sandy Valley.
3. District tributary to the Louisville and Lexington Railroad, or Chesapeake and Ohio Railway district.
4. Little Sandy Valley, or main Eastern Kentucky Railway district.
5. District tributary to the southern terminus of the Eastern Kentucky Railway.

OHIO DISTRICT.

EXTENT.

Only the southern part of Lawrence County, Ohio, including parts of Fayette, Perry, and Upper townships, is included in the Kenova quadrangle.

STRATIGRAPHY.

The rocks exposed in Ohio comprise the whole of the Allegheny and parts of the Conemaugh and Pottsville formations. The total thickness represented is in round numbers about 600 or 700 feet. The following section, obtained near Coalgrove depot, gives an excellent idea of the Allegheny formation and the lower part of the Conemaugh as developed at this point. The numbers of the coals are those of the Kentucky series.

Section near Coalgrove depot.

	Feet.
Conemaugh formation:	
Sandstone, laminated	25
Shale, red and green	25
Limestone, fossiliferous (Cambridge)	1
Sandstone, laminated	20
Shale	10±
Sandstone, laminated	36
Allegheny formation:	
Coal bloom (*position of coal No. 9*).	
Concealed	50
Position of coal No. 8.	

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Allegheny formation—Continued.	Feet.
Concealed and shaly sandstone	44
Coal No. 7.	
Sandstone, massive	33
Coal No. 6.	
Sandstone, massive	40
Clay, massive flint	1½–1⅞
Clay, plastic	5
Limestone ("Hanging Rock")	4
Fire clay	1⅞
Concealed	5
Probable position of coal No. 4.	

The Conemaugh formation in the Coalgrove section is typical so far as it goes, with the exception of the basal sandstone. This is not usually laminated, but is very massive near the eastern edge of the quadrangle (Pl. III, *B*, p. 14). The massive character of this basal member is well shown near the Norfolk and Western Railway bridge near North Kenova and on the county road joining the river pike west of Burlington. This sandstone forms prominent cliffs nearly all along Ohio River in this area and in West Virginia as well. The higher beds of the Conemaugh, not shown in the section at Coalgrove, are well exposed in the hills back of Burlington and Sybene and in general away from Ohio River, and consist chiefly of red shale and sandstone, occasional limestones, which are more or less persistent, and small coal beds, rarely of workable thickness. In the eastern part of the Ohio district, in Fayette Township, the surface of the country is made up chiefly of shales of the Conemaugh, with local sandstones and small and unimportant coal beds. This region, though very hilly, is fertile and well adapted to the growing of fruits and farm products, and is under general cultivation (Pl. III, *A*, p. 14). Since this formation is of little economic interest, it will not be considered further.

The Allegheny is fairly developed, with the exception of coal No. 4[a] (Ohio nomenclature, Pl. IV). This coal was not seen in the section at Coalgrove, but the higher coals were all seen at one point or another in this State. The Allegheny formation is present in all the hills in Upper and Perry townships, but the eastern dips cause it to disappear near North Kenova, just east of the Norfolk and Western Railway bridge. The thickness of the Allegheny is about 180 feet. The highest coal bed present in this formation is the Upper Freeport, which lies either immediately or at a small distance below the Mahoning sandstone. Its bloom is fairly widespread, though it does not seem to have been worked to any extent. This coal is the Waterloo or No. 7 of the Ohio Geological Survey. Thirty to fifty feet below it occurs the Hatcher of the Ohio and Kentucky geological surveys.

[a] No. 5 in the Kentucky series.

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In Ohio it is No. 6A and in Kentucky No. 8. E. McMillan[a] has correlated it with the Lower Freeport of Pennsylvania. The most important coal in this part of Ohio is found 100 feet below the base of the Mahoning sandstone. It is known as the Sheridan or No. 6 coal in Ohio. In Kentucky it is also important and is known as the No. 7 or Coalton coal. The Ohio geologists[a] have correlated it with the Middle Kittanning coal. Between these three coals are two beds of limestone, in many places associated with iron ore. The massive sandstone overlying the Coalton coal serves as a means for locating and following it. About 30 to 40 feet below the Coalton coal another persistent bed is found, known as the Newcastle coal, or No. 5 bed (No. 6 of Kentucky). It is best seen at Coalgrove, where it lies 33 feet below the Coalton coal, the interval being occupied by a very massive sandstone.

The lowest stratum of economic importance in the Allegheny is the clay associated with the Vanport ("Hanging Rock") limestone. The bed is about 75 feet below the Coalton coal and is capped by a very massive sandstone. No other beds of economic value were seen above drainage level in this area.

Only a very small part of the Pottsville formation is shown, probably not more than 20 to 25 feet, and this is in the vicinity of the Coalgrove section. The Homewood sandstone outcrops near Coalgrove depot, and although No. 4 coal of the Ohio Survey, or that resting directly on the Homewood sandstone, is not known in this immediate neighborhood, it has been recognized in the vicinity of Ironton, not more than a mile to the west, by the Ohio geologists.[b]

THE COALS.

UPPER COALS.

The upper coals in the Allegheny formation and the coals in the Conemaugh have little or no importance in this part of Ohio. The Hatcher coal, No. 8 of the Kentucky Survey, and the Upper Freeport have been opened in a few places on Lick Creek, about 1½ miles east of Sheridan, and near the residence of R. H. Henshaw on Little Ice Creek. In the summer of 1905 openings on these upper coals were fallen shut and no measurements could be obtained. According to the Ohio State reports the Upper Freeport coal, which is known as the Bayleys Run or Waterloo coal, is 4 feet thick near Ironton,[b] and in the general section given by McMillan[a] it is represented as averaging 6 feet. In quality these coals are inferior to the

[a] Ohio Geol. Survey, vol. 5, 1884, p. 122.
[b] Ohio Geol. Survey, vol. 3, pt. 1, 1878, section opposite p. 928.

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Coalton coal, and under present conditions probably could not be marketed. They have furnished up to the present time a small amount of fuel for local consumption and will probably continue to do so for a number of years.

SHERIDAN COAL OF OHIO (COALTON COAL OF KENTUCKY).

Position.—The Coalton coal is 100 feet below the Upper Freeport coal and about 50 feet below the Hatcher or Lower Freeport bed. It has been correlated with the Middle Kittanning coal of Pennsylvania. In this report the name Coalton coal will be applied to this bed, since in Kentucky it was originally worked at Coalton, and was widely known under this name.[a] It is the second bed above the Vanport ("Hanging Rock") limestone and ore.

Extent.—This coal has been known and worked for many years in the Hanging Rock region. According to the Ohio Geological Survey reports,[b] it is identical with the celebrated Nelsonville or Straitsville coal of the Hocking Valley. Up to the present time it has proved to be by far the most important commercial coal in this quadrangle, and in Kentucky much of it lying above drainage level has been removed. In Ohio, however, little has been removed above drainage level and none below.

As it occurs 30 to 40 feet above the next lower coal its outcrop will be found above drainage level farther to the east than the outcrop of the lower bed, but the area above drainage level underlain by it is comparatively small, being not more than one-tenth of that part of Ohio included within this quadrangle. It is present in all the hills near Coalgrove, Forestdale, and Sheridan; in the hills well up on Little Ice Creek, and also along Ohio River to a point about 2 miles above Sheridan. (See Pl. I.) Beyond this point it is hidden by the flood-plain deposits. Near North Kenova, just east of the bridge, no flood plain is present, and a coal which may possibly be referred to the Coalton bed lies nearly at the river's edge. It is about 55 feet below road level and is now worked in a small way by B. J. Davidson and Will Dillon. West of the bridge a few old openings on this bed were observed, but they are fallen shut and the thickness of the bed could not be determined. Just east of the Davidson and Dillon openings the coal disappears below Ohio River.

Development.—This coal is not now worked on a commercial scale, but the reason is evidently not the scarcity of material, as there is an ample supply of good coal still above drainage level. The old Sheridan Company ceased operations more than twenty years ago.

[a] Kentucky Geol. Survey, vol. C, 1884, p. 122.
[b] Ohio Geol. Survey, vol. 3, pt. 1, 1878, pp. 917–918.

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At present the coal is of importance simply as a source of local supply and has been opened at many points where its outcrop approaches drainage level, notably on Little Ice Creek and its branches east of Forestdale, and in the hills along Ohio River near Sheridan.

Character.—The Sheridan coal in general ranges in thickness from about 3 to 4 feet, but in places exceeds the latter figure. As a rule it has a small bony parting, an inch or less thick, lying from 2 to 14 inches from the roof. The upper of its two benches is usually about a foot thick; the lower or main bench varies from 2 to 3 feet. Southeast of Lick Creek the two benches are represented by a single bench of 25 to 27 inches (section 3, fig. 1). The different measurements of this bed obtained in this field are given in fig. 1. It is possible that a third bench exists in places, for in Kentucky this very commonly appears.

The Coalton coal is a hard, splinty coal, breaking along charcoal layers into slabs, which range from 6 to 8 inches in thickness. It is

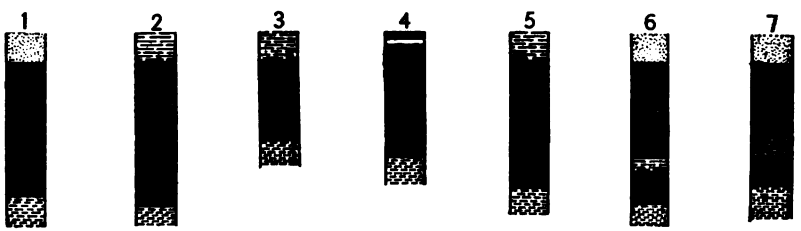

FIG. 1.—Sections of Allegheny coals in Ohio. Coal No. 7: 1, Elizabeth Wise, Little Ice Creek; 2, John Ide, Sheridan; 3, William Talbot, 1 mile southeast of Sheridan; 4, Henry Wineka, Lick Creek; 5, east of Forestdale. Coal No. 6: 6, country bank north of Coalgrove; 7, Harry Smith, north of Coalgrove. Scale, 1 inch = 5 feet.

too high in sulphur to make a first-class coke, therefore it will be used chiefly as a steam and domestic coal, being well adapted for stove and grate use. The analyses of this coal, given on page 71, are discussed on pages 71–72.

The roof of the coal is in some places massive sandstone and in others shale. The sandstone which overlies or underlies the coal becomes abnormally thick in places and cuts it out almost completely, leaving but a few stringers of coal to represent the bed. Such is its condition along the Ohio River, opposite the eastern suburbs of Ashland, where the sandstone of the lower part of the Allegheny formation is abnormally thick. For this reason the coal is not visible in many places where its horizon is exposed. It is reported also to be absent just west of Forestdale.

Economic features.—Owing to the southeast dips which prevail in this district the proper points for opening mines on this coal bed are on the southeast flanks of the hills. In sinking shafts care should

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be exercised to place them with a view to working up the dip or in a northwest direction. The situation of the district with respect to market and transportation could hardly be improved. Many of the large cities of Ohio and Kentucky lie within a radius of 100 miles, and either railway or the very much cheaper river transportation is convenient, the Ohio being navigable the year around well above this point.

No estimate is attempted of the amount of coal of workable quality. It may be sufficient to state here that the Coalton bed underlies about nine-tenths of that portion of Ohio included in this quadrangle, and there is no apparent reason for supposing that it will not prove workable in almost its entire area.

NEWCASTLE COAL OF OHIO (WINSLOW COAL, OR NO. 6, OF KENTUCKY).

Extent and development.—The lower of the workable coals in Ohio has been called in the State reports the Newcastle or No. 5 coal, and is considered by Orton and the Ohio geologists as the equivalent of the Lower Kittanning coal of Pennsylvania. (See Pl. IV, p. 28.) As it is the first coal bed of importance above the Vanport ("Hanging Rock") limestone, it is locally called in Kentucky the "Limestone coal," a name which is also applied to it about Coalgrove, Ohio. It is worked on a commercial scale at Winslow, Boyd County, Ky., and therefore will be called in this report the Winslow coal. It is found at varying distances above the Vanport limestone, but it will average 40 feet above this bed and 30 feet below the Coalton coal. From the sections given on page 36 and in fig. 1 it will be seen that this coal lies below heavy sandstones at Coalgrove. Its outcrop is not indicated on the economic map, but, if drawn, would appear between that of the Vanport limestone, represented in red, and that of the Coalton coal, represented in blue. It will be seen that its outcrop is not of great extent, because the eastern dips carry it below drainage level. Where exposed it has been opened in many places, and it is now mined on a commercial scale near the base of the hill northwest of Coalgrove depot. Several country banks are working this coal near Forestdale, east of which the coal is below drainage level. Along the river pike this coal has been worked in a very small way at one or two points, but the linear extent of its outcrop here does not exceed a mile.

Character.—The two sections given in fig. 1 (p. 34) illustrate well the character of this coal. The first section, obtained just north of Coalgrove depot, is more typical than that measured at the country

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bank of Harry Smith, as the bed usually occurs in three benches, which may vary as shown in the following section:

General section of Winslow coal, near Coalgrove.

Sandstone.	Inches.
Coal	8–16
Bone	1– 3
Coal	15–16
Shale	4
Coal	8–16

The bed is apt to be irregular in thickness, and the maximum figures given above were obtained at only one point. A fair average thickness is 3 or 3½ feet. The massive sandstone which overlies the bed furnishes an admirable roof, and little timbering is necessary. On the other hand, this sandstone is liable to roll and it may replace the coal completely. The coal is dry, of good quality, and well adapted for heating purposes. It does not furnish a good grade of coke, owing to the presence of a large amount of sulphur, but after washing it is suitable for coking. The coal mined at Coalgrove is shipped over the Norfolk and Western Railway to Portsmouth, Ohio.

BIG SANDY VALLEY DISTRICT.

EXTENT.

The Big Sandy Valley district includes that portion of this quadrangle whose natural outlet is along Big Sandy River. It includes all of Wayne County, W. Va., within the limits of this quadrangle, except that part whose outlet is along Twelvepole Creek; but as this small area is of little importance from an economic standpoint, it may be said that all of West Virginia included in this quadrangle has its natural commercial outlet along Big Sandy River. This district extends as far west as the ridge dividing the waters of Big Sandy from those of East Fork of Little Sandy River. The northwestern corner of this division is the summit of the ridge between Shope and Chadwick creeks, Boyd County. Southwest of this point the boundary is a sinuous line along the ridge mentioned, which lies east of Alley, Bolts Fork, and Estep. In this district is included Cooksey Fork and Cat Creek. From the head of Cooksey Fork the line marking the western boundary of the district passes to the confluence of Daniels Creek and Blaine Creek, thence along the latter creek to the south. It passes out of the quadrangle along the ridge immediately west of Rich Creek. (See Pl. I.)

STRATIGRAPHY.

This district includes the widest range of coals in the entire quadrangle, comprising, indeed, all the coal horizons here represented. All the coals, however, are not developed in this district on a work-

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able scale, and a few beds appear not to have been formed at all in places. On account of the comprehensive character of the geologic column the description of this district will serve as a natural introduction to those which follow.

All the geologic formations represented in the quadrangle, with the possible exception of those of the Mississippian series, are developed in the Big Sandy Valley. The highest rocks represented belong to the Monongahela formation. This formation is only partly developed and is of very small extent, occurring in the hills which carry the Pittsburg coal near the mouth of Gragston Creek, Wayne County, W. Va. This is the only locality in this quadrangle where rocks of this formation are present. Its most important member is the Pittsburg coal lying at its base. This is capped by the Pittsburg sandstone, which is about 30 feet thick and is very massive. The remainder of this formation is composed of reddish shales and sandy sediments. About 100 feet of the formation are still left in the hills. (See Pl. IV, p. 28.)

The Conemaugh formation is completely developed in a small area in this quadrangle near the mouth of Gragston Creek, Wayne County, W. Va., in the deepest part of the basin. In the tops of the highest hills near the mouth of this creek is the Pittsburg coal mentioned in the last paragraph, the floor of which marks the top of the Conemaugh formation. The thickness of the Conemaugh is more than 300 feet. It is composed chiefly of shales, together with limestone and a few thin coal beds. It also contains sandstones which, with certain exceptions, are liable to be lenticular, and on this account are poor stratigraphic guides. The rocks of this and the overlying Monongahela formation are the poorest in the area with reference to coal resources, the only really valuable coal associated with them being the Pittsburg bed, which occurs in too small an area to be of great economic importance. The rocks of this formation, although a complete section is shown only over a very small area, are yet widespread over the surface of this district, occupying possibly two-thirds of the entire area.

The Allegheny, the next lower formation, is about 160 feet thick. A section of Allegheny rocks may be seen along the road northwest of Louisa from a point near the confluence of Canes Branch and Twomile Creek. The massive sandstone at the top of the Pottsville is in the roadbed at drainage level, and not far away the Winslow, or No. 6, coal bed has been opened 30 feet above it. At the forks of the road near the head of Canes Branch one of the lower limestones of the Conemaugh formation is present, with another limestone 40 or 50 feet below it on the west side of the ridge. The Mahoning sandstone, lying 50 feet under this lower limestone, is rather massive. West of this ridge, as Blaine Creek is approached, the sandstone at the top of

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the Pottsville becomes abnormally massive and thick. The Allegheny here loses some of the distinctiveness which characterizes it in the northern part of the quadrangle, and its upper boundary is somewhat doubtful. Southward from the region around Louisa the rise in the beds causes the gradual disappearance of the Allegheny from the hills. North of this point the formation gradually descends to the center of the basin, until at Zelda the highest coal in the formation disappears below the flood-plain deposits. A rise in the beds brings the Allegheny above drainage level again north of Savage. The formation is present in whole or in part in nearly all the hills in the southern third of the Big Sandy Valley district and also at the north end of the district near the mouth of Big Sandy River. The coals of the Allegheny are not so well developed in this district as to the north and west. The thickness of the formation along Big Sandy River, north of Louisa, seems to be about the same as near Ashland and Coalgrove, 160 to 180 feet.

The Pottsville formation is well developed in the southern part of the district, and a fairly good section was compiled on the Chesapeake and Ohio Railway, along Levisa Fork and in the surrounding hills. This section was measured south of Louisa and is as follows:

Section of Pottsville on Levisa Fork south of Louisa, Lawrence County, Ky.

	Ft.	in.
Sandstone, massive, Homewood[a]	40–60	
Coal No. 4, Lick Creek coal (Upper Mercer).		
Ore, black band	8–12	
Concealed	20	
Sandstone, massive	20	
Shale or sandstone	15	
Coal No. 3, Torchlight (Lower Mercer).		
Probable shaly sandstone	50–60	
Coal		4–8
Probable sandstone	21	
Concealed, but probably shaly sandstone	19	
Concealed	17	
Sandstone, laminated	5	
Concealed	20	
Shale with five small coal beds, the topmost of which is the so-called "Little Cannel seam"	32	8
Sandstone, massive	40–100	
Interval	30±	
Shale, drab	5	
Shale, black	3	
Shale, dark	4	
Coal (Sharon?)	1	4

[a] It is probable that south of Louisa, where this sandstone is very massive and apparently homogeneous throughout, it is not wholly of true Homewood age. Its lower part probably belongs under coal No. 4, which was cut out in places by a thickening up of the lower sandstone member. In this case only the top should be regarded as the true Homewood sandstone.

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	Ft.	In.
Shale and sandstone	5	
Coal bloom		6
Sandstone, massive (Sharon)	40±	
Shale	10	
Coal bloom	1	
Shale and sandstone	10	
Shale	5	
Limestone, blue		8
Shale, gray	2–5	
Limestone, blue	1	
Shale, dark	5	
Sandstone	4	
Shale	3	
Coal bloom	1–2	
Shale	3	
Coal bloom.		
Sandstone, massive	4	
Coal bloom.		
Fireclay		8
Sandstone		1½
Concealed	20±	
Sandstone, shaly, micaceous	10	

It will be seen that in general the section shows several massive sandstone groups, between which are intervals containing coals, shales, shaly sandstones, limestone, and iron ores, the total thickness of which is approximately 600 feet. The general sandy character of this formation is also noteworthy.

In the section certain Pennsylvanian equivalents have been inserted in parentheses. These correlations have been based on studies made by David White. The bed worked at Torchlight, known at the Torchlight coal in this report, is regarded by him as the equivalent of the lower coal worked at Boghead, Carter County, and both the lower and the upper coals worked on Stinson Creek at Boghead fall within the Mercer group of northwestern Pennsylvania. It would seem, therefore, that the Torchlight (No. 3) and No. 4 probably correspond to the lower and upper Mercer coals, respectively.

The reference of the group of thin coals, of which the "Little Cannel" is one, to the Sharon or No. 1 horizon is furthermore not sustained by the paleobotanic evidence, according to White. This group occurring in the interval of 32 feet 8 inches at railway level north of Torchlight represents a higher horizon than the Sharon. The coal underlying the massive sandstone, which begins to be prominent in the hills back of Chapman, is probably the representative of the Sharon in this section. At Gallup a lower sandstone is 50 to 60 feet above railroad grade, and a short distance north of the store it is 50 feet thick. This is probably the Sharon sandstone.

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It will be observed that the portion of the Pottsville below the sandstone at Gallup (Sharon) is characterized, within the limits of the quadrangle, by the development of dark shales and gnarly cauda galli flags, including some limestones and coals of variable thickness.

THE COALS.

MONONGAHELA COAL (PITTSBURG BED).

In the tops of the hills near the center of the basin there is about 100 feet of the Monongahela formation. At its base is a coal which is referred to the horizon of the Pittsburg bed, though it is hardly comparable in thickness with this famous bed in West Virginia and Pennsylvania. It is nevertheless a coal of excellent quality, and only its very moderate area of not more than a few acres prevents its commercial exploitation. In the hills east of Lett, at the mouth of Gragston Creek, it has been opened on the land of Abraham Thacker and James Adkins, and is found to range in thickness from 2½ to 4½ feet. It averages about 3 feet and usually has a thin but strong shale roof overlain by massive sandstone 20 to 30 feet thick. The section obtained at one of the openings on the land of James Adkins illustrates the character of this bed (see fig. 2).

FIG. 2.—Section of Pittsburg coal at bank of James Adkins in hill west of Centerville, W. Va. Scale, 1 inch = 5 feet.

CONEMAUGH COALS.

It has been stated that the Conemaugh formation is in marked contrast with that lying below, both in the character of its rocks and in the fact that it contains no workable coals and only here and there a bed of iron ore. In the Big Sandy River Region this description holds fairly good with one exception. In the hills back of Cassville a small coal, called by I. C. White[a] the Mason coal, is found in the group of sandstones at the base of the Conemaugh. It is 2 feet thick. The same coal bed has been opened at a few points along Twelvepole Creek a few miles above Ceredo. It is as a rule so thin and so variable in its distribution that it can hardly be classed among the important coals of the future. It has now and may continue to have some local importance. With the exception of this bed the Conemaugh formation is probably devoid of workable coals.

[a] West Virginia Geol. Survey, vol. 2, 1903, p. 280.

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ALLEGHENY COALS.

SECTIONS OF THE FORMATION.

The base of the Allegheny formation appears in the hilltops about 7 or 8 miles south of Louisa and dips rather steeply to the north, being very nearly at railroad grade at Eloise and a few feet below railroad level at Louisa. There are at least five workable coals in the Allegheny in different parts of this quadrangle, but in no single district are all these of workable thickness. Usually not more than two or three are workable in any particular locality. This is true for the region about Louisa and for the valley of Big Sandy River as a whole. A section obtained near Cassville will illustrate the character of the beds in the Allegheny formation.

Section at Cassville.

Top of hill.	Ft.	in.
Concealed and sandy débris	15	
Sandstone, massive	28	
Shale	3	
Shale, fossiliferous[a]	4	
Coal	2	
Sandstone, conglomeratic in places, with calcareous nodules about 15 feet from its top	53	
Probable top of Allegheny.		
Concealed	22	
Sandstone, massive	20	
Clay, flint.		
Shale, green	1	6
Shale, red	1	
Shale	12	6
Concealed, but containing a coal near the top	20	
Sandstone, laminated or shaly	1	
Shale, sandy	9	
Shale, greenish, and sandy shale	25	
Coal smut		2
Fire clay, green	3	
Sandstone	2	
Fire clay, drab	1	6
Shale, sandy	12	
Sandstone, massive	4	
Fire clay		3–4
Sandstone, laminated	19	
Limestone ore, nodular	1	
Shale	3	6
Coal No. 6	1	9
Fire clay, upper part fossiliferous	2	
Shale, sandy	6	
Coal		1½

[a] This shale is regarded by I. C. White as the representative of the lower Cambridge limestone and the coal underlying it as the Mason: West Virginia Geol. Survey, vol. 2, 1903, p. 280.

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	Ft.	in.
Shale, green, fossiliferous	1	
Coal		5
Fire clay		6
Fire clay, siliceous	6+	
Concealed	7	6
Railroad grade.		

The lower part of this section was measured also in the first main cut on the Chesapeake and Ohio Railway, about a mile north of Louisa.

This section, which shows the variations that may take place within a short distance, is as follows:

Section north of Louisa.

	Ft.	in.
Coal	1	
Sandstone, laminated	2	
Coal		6
Shale	3–5	
Sandstone, laminated	4	
Fire clay		6
Sandstone, laminated	2	
Limestone, ferruginous		4–5
Fire clay	1	
Sandstone, laminated	2–3	
Fire clay, with nodular limestone	1	
Sandstone, laminated	3	
Limestone nodules, intermittent layer		6
Shales, drab, or fire clay	4	
Coal, changing to black flint		6
Fire clay	2	
Coal	1	6
Shale, dark fossiliferous	4	
Bone		6
Shale, drab fossiliferous	1	6
Coal		6
Fire clay, siliceous	5	
Railroad level.		
Fire clay, siliceous	3	
Concealed	3	
Shale, drab	5	

These two sections, obtained on opposite sides of the confluence of Tug and Levisa forks, illustrate well the character of the coal-bearing rocks in this vicinity. The sandstone member forming the top of the Pottsville is exposed at the mouth of Lick and Mill creeks, south of Louisa and Cassville; also at the lock just a short distance down Big Sandy River from Louisa, and at the mouth of Canes Branch. Its top, therefore, must be only a few feet below the flood plain on which the towns are built. This statement is corroborated by the evidence of the fossil plants, examined by David White, from the fossiliferous beds indicated in the lower parts of the above sections.

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ZELDA COAL (NO. 9).

Name and position.—The Zelda coal is the No. 9 of Kentucky and the No. 7, Bayleys Run, or Waterloo coal of Ohio.

The highest coal of importance in the Allegheny formation in Big Sandy Valley usually occurs below a rather massive sandstone which, for reasons already stated, is regarded as the Mahoning sandstone. The coal below this sandstone, the Zelda coal, is thought to occur at the horizon of the Upper Freeport coal.

Extent and development.—In the valley of Big Sandy River the Zelda coal has been prospected at a number of points. The rise of the beds up Big Sandy River brings this coal above drainage at

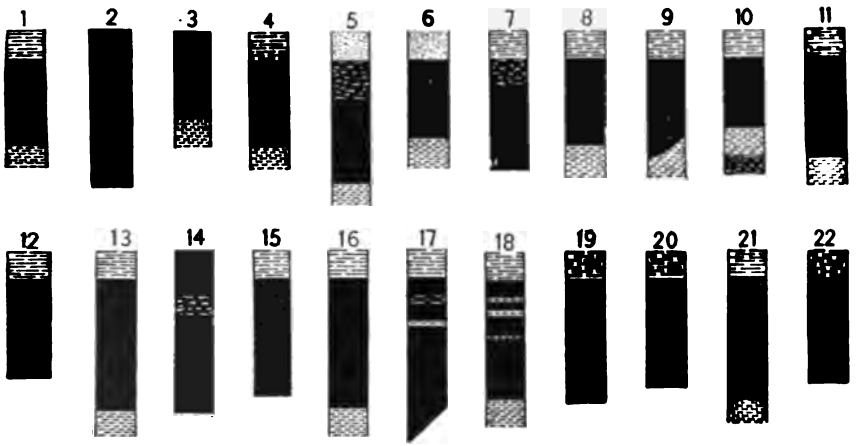

FIG. 3.—Sections of Zelda coal (Upper Freeport, Kentucky No. 9). Kentucky: 1, Clifton Dean, near Zelda; 2, Frank Yates, near Catalpa; 3, 1 mile north of Fallsburg; 4, Matthew Holley, mouth of Cat Creek; 5, 1 mile above No. 4; 6, C. C. Crank, Fallsburg; 7, west of Fallsburg; 8, John Bentley, Yatesville; 9, Wade Chapman, Yatesville. West Virginia: 10, on Norfolk and Western Railway, north of Miller Creek; 11, Alvin Stewart, opposite Zelda; 12, mouth of Little Hurricane Creek; 13, Christopher Bellamy, Little Hurricane Creek; 14, Elijah Thompson and William Wellman, Little Hurricane Creek; 15, Isaac B. Fish, Tabor Creek; 16, John Thompson, Long Branch of Tabor Creek (only main bench is shown); 17, Volney Artrip, head of Right Fork of Hurricane Creek; 18, head of Trace Branch; 19, 20, 21, near Bellups Gap; 22, Tug Fork. Scale, 1 inch = 5 feet.

Zelda, where it has been opened on both the Kentucky and the West Virginia side of the river. Just south of Zelda 26 inches of coal were measured at the bank of Clifton Dean (fig. 3, section 1). A short distance north of Dean's bank E. D. Milan has opened the same coal. South of Zelda it has been opened and worked in at least half a dozen places near the mouth of Mill Branch and at Gurnetts, where it ranges from 2 to 3 feet in thickness. Southwest of Catalpa it has been opened by Frank Yates, of Louisa, 48 feet above the railroad track, where it measures a little over 4 feet thick (fig. 3, section 2). This coal has also been opened near the mouth of Horseford Creek, on the property of Dr. John Berry, of Quincy, Ky. At this point

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only 1 foot of coal is exposed, beneath a shale and sandstone roof, but the bed is reported to be 3 feet thick. South of Fuller, owing to the rise of the beds, the massive sandstone capping this coal may be seen from the railroad at a few points; but the coal underlying it has not been opened, except near the heads of some of the shorter streams which flow into Big Sandy from the west.

Fallsburg district.—The rise of the beds toward the south brings the coal bed above drainage level on Blaine Creek at the mouth of Long Branch, about 1 mile north of Fallsburg. Here it has the section indicated in fig. 3, section 3. A short distance to the south, near the mouth of Cat Creek, a section (4, fig. 3) almost identical with section 3 was seen at Matthew Holley's bank. The coal farther in the bank is reported 33 to 34 inches where thickest. About a mile farther up Cat Creek a section (5, fig. 3) showing about 25 inches of coal furnishes added evidence of the uniformity of the coal in this vicinity. The following section was measured east of Fallsburg:

Section east of Fallsburg.

	Feet.
Soil, sandy.	
Limestone débris.	
Soil, clayey.	
Shales, green	60
Sandstone	5
Limestone, crinoidal	2–3
Fire clay	1
Shale, red and green	20–25
Shale	20
Clay	4
Sandstone	45
Sandstone, massive	20
Coal bloom, Zelda.	

This section shows well the character of the beds above the Zelda coal in this region. The coal at the base of the section has been opened at a number of country banks in and about Fallsburg, where it averages about 2 feet thick, as sections 6 and 7 (fig. 3) show. West of Yatesville, at the banks of John Bentley, Wade Chapman, and James Compton, the coal bed is reported as ranging from 2 to 3 feet, and these figures were verified in several places (sections 8 and 9, fig. 3).

West Virginia.—The sandstone overlying the Zelda coal disappears below drainage level a short distance north of Zelda and is not exposed again until it rises above drainage level on the north side of the basin near Savage, Ky. From this point to the mouth of Big Sandy River no coal was seen immediately below the sandstone, but in a bed of shale, 20 feet or so below, an occasional bloom was noticed which may correspond with Crandall's No. 8, or the Hatcher bed. In West Virginia, near the mouth of Big Sandy River, the basal

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sandstones of the Conemaugh are a very conspicuous feature in the landscape, and in recent cuts along the Norfolk and Western Railway a coal bed occupying a position corresponding to that of the Zelda coal was observed near the mouth of Miller Creek. This is the coal bed worked by Will Payne, a short distance above the mouth of the creek. It is reported to be 32 inches thick at Payne's bank, though, as will be seen from section 10 (fig. 3), it is very badly split by partings along the railroad. South of Neal it disappears below the flood plain. Farther east, on Whites and Gragston creeks, the horizon of this coal is above drainage, and in a few places the bed attains a workable thickness. Opposite Zelda, at Alvin Stewart's, the coal shows a thickness of very nearly 40 inches (section 11, fig. 3). About Hubbardstown and along Hurricane Creek both this coal and the next underlying bed outcrop in several places. The lower of these two coals is rarely of workable thickness, but the higher coal has been opened in several places and shows a thickness of 2½ to 3 feet and more (sections 12, 13, and 14, fig. 3). About a mile east of Hubbardstown the bed does not appear to be of sufficient thickness to work, but near the mouth and near the headwaters of Tabor Creek it has an average thickness of 3 feet (section 15, fig. 3), and in places, instead of a single bench, consists of two benches, as indicated in the following section, measured at the bank of John Thompson:

Section at John Thompson's bank, Tabor Creek.

	Inches.
Sandstone roof.	
Coal	6½
Shale and fire clay	37½
Coal	39½
Fire clay.	

Northeast of Cassville, on the headwaters of Right Fork of Hurricane Creek, and still farther northeast, on Trace Branch, sections (17 and 18, fig. 3) measured at the country banks working this coal give a good idea of its persistence and character. This coal has also been opened at one or two points on Mill Creek.

The coal opened just north of Bellups Gap is tentatively referred to this bed, but it may be a lower coal. It has been opened by Poley Ferguson and James Bellup. This is probably the same coal opened less than a mile northeast of Louisa, which has a similar section (sections 19, 20, and 21, fig. 3). The coal opened near Copley on Tug Fork is also regarded as a lower bed than the Zelda coal and may possibly be as low in the formation as the Coalton coal (section 22, fig. 3).

Character.—From sections of the Zelda coal given in fig. 3, it will be seen that it consists in general of a single bench ranging in thickness from 2 to 3 feet. It usually has a thin black shale or bone roof,

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but is in many places overlain by massive sandstone. It rarely exceeds 2½ feet in thickness, and the measurement of 4 feet obtained at Frank Yates's bank, southeast of Catalpa, is apparently local. The coal is a lustrous, bituminous, semiblock coal, with splinty partings, and is highly esteemed for smithing and domestic purposes. The chief objection is to its thin section. Its quality apparently bears a certain relation to the thickness of the bed, for the thicker coal is reported to be of poorer quality at the head of Little Hurricane and Tabor creeks. It is quite probable that it will prove commercially valuable at some future time in the area indicated by the solid outcrop line. (See economic map, Pl. I.)

COALTON COAL (NO. 7).

The Coalton is the next lower coal bed in the Allegheny formation. Taken as a whole, this coal is the most important in the entire quadrangle, but in the valley of Big Sandy it is of minor importance. About two-thirds of a mile south of Potters a coal referred to this

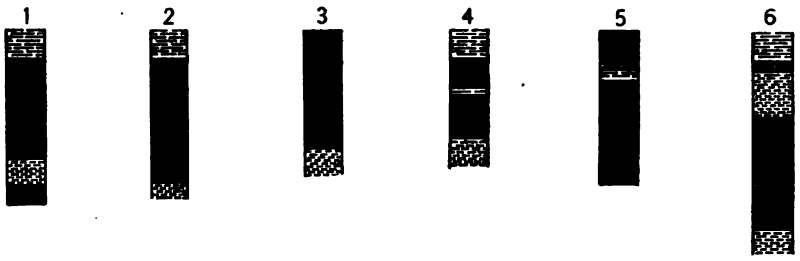

FIG. 4.—Sections of the Coalton and Winslow coals in Big Sandy River district. Coal No. 7 (?): 1, George Cooksey, Cat Creek; 2, Cat Creek; 3, Cat Creek. Coal No. 7: 4, two-thirds of a mile south of Potters. Coal No. 6: 5, T. J. Chapman, Lick Creek; 6, John Vaughn, Lick Creek. Scale, 1 inch = 5 feet.

horizon outcrops at railroad level, but is thin (fig. 4, section 4). This coal has been worked just north of the station.

On Cat Creek, below the mouth of Thompson Fork, a coal which is doubtfully referred to this horizon has been opened about 40 to 50 feet above the road. It is closely overlain by a rather massive sandstone, and in this respect resembles the Coalton coal, but the distance below the base of the massive sandstone forming the lowest member in the Conemaugh formation points to a higher bed. It may therefore be the next higher, or Hatcher, coal. Along Cat Creek it is not over 50 feet below the base of the Mahoning sandstone, whereas the ordinary distance below that sandstone of coal No. 7, or the Sheridan bed, around Ohio River is from 90 to 100 feet. It is certain that the usual number of coals is not developed in the Allegheny rocks along Cat Creek below the mouth of Thompson Fork, as the section in the hill between Cat Creek and Morgan Run indicates. The coal under

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consideration has been opened on the property of W. A. Rice, John Cooksey, Willis Roberts, J. K. Chadwick, Mrs. Americus Wood, and Mrs. Nancy J. Carter, on Cat Creek, and also in the vicinity of Yatesville. Sections 1, 2, and 3 of fig. 4 illustrate the character of this bed in the valley of Blaine Creek.

WINSLOW COAL (NO. 6).

In the section given on page 42, above the railroad level a mile north of Louisa, there is a bed of coal 1½ feet thick 11 feet above the railroad track. In places this coal measures from 27½ to 29 inches, with a drab or black shale roof a foot or two thick and a clay floor. It is the same bed which has been opened in the hills west and northwest of Louisa and is probably the coal referred to as coal No. 6 in Crandall's report; also, it is probably the bed which is mined so extensively about Ashland and Winslow, in Boyd County, and at Coalgrove, Ohio. At these different places it is known as the limestone coal, from its position as the first coal above the Vanport ("Hanging Rock") limestone. Though it is worked extensively about Ashland, it has been thought best not to apply the name of that city to it, as the coal next above (the Coalton coal) is frequently referred to in the Ohio reports as the Ashland coal.[a] It is being mined and shipped from Winslow, south of Ashland, and hence may appropriately be known as the Winslow coal. In the Ohio reports it is usually termed the Newcastle coal. As the first coal above the Vanport limestone it corresponds, in position at least, with the Lower Kittanning or Miller bed of Pennsylvania.

Though this coal bed has been opened in many places near Louisa, only a few measurements could be obtained, as nearly all the banks in which the coal has been worked have fallen shut. Near the mouth of Twomile Creek and on Lick Creek it has been opened and worked on a small scale. This is probably the coal opened by John Vaughn and T. J. Chapman. (See fig. 4, sections 5 and 6.) It is reported of workable thickness in the hills north of Chapman's store on Threemile Run, and a few old openings on it were seen at this place. On Dry Ridge south of Irad it appears as a small coal not exceeding 2 feet in thickness.

In West Virginia, south of Cassville, it has been opened, and 32½ inches of coal were seen at an opening south of the town. On Mill Creek the coal has been opened at a few points, and though the upper part of the bed is somewhat injured by the presence of bone and shale, it usually contains a lower bench of bright, lustrous bituminous coal of good quality, averaging from 2 to 3 feet in thickness.

[a] Ohio Geol. Survey, vol. 3, pt. 1, 1878, p. 918.

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CAT CREEK COAL (NO. 5).

Position.—The lowest workable coal in the Allegheny formation in the Big Sandy Valley district occurs below the Vanport limestone. This coal usually lies directly on, or a very few feet above, the Homewood sandstone. Where the two sections given on pages 41–42 were measured, it may be below the lowest member shown and hence not appear in the section. This coal is regarded as the equivalent of the main workable bed on the headwaters of Cat Creek, and as it probably attains its maximum development in that region and is generally known in this part of Kentucky as the Cat Creek bed, it will be called in this report the Cat Creek coal. Crandall, in his general section of this part of Kentucky, has placed No. 5 coal, to which he gives the names Cooksey Fork and Pennington coal,[a] as the first below the horizon of the Vanport limestone, and therefore it appears probable that Crandall's No. 5 or Cooksey Fork coal is the same as the Cat Creek bed of this report. Crandall states that this coal occurs 30 to 40 feet below the limestone ore, referring to the ore associated with the Vanport limestone. This distance is rather large for the region about the head of Cat Creek.

Extent and development.—About Louisa the presence of this coal is nearly always indicated by a bloom. Its position above the Homewood sandstone is best seen in the gorge of Lick Creek near its mouth, and on the Lick Creek pike. About 2½ miles southwest of Louisa it has been opened by Mordecai Wilson, but the bank is now fallen shut. Near Osie coal has been dug, but the bed is reported to be thin. In West Virginia, south of Cassville, this coal is usually present, but is thin and, as on the Kentucky side, is very rarely worked. A short distance south of Louisa it is below the flood plain. In the immediate valley of Big Sandy and its tributaries to the south it will probably not prove workable over any considerable area.

This coal is the most important bed on the headwaters of Cat Creek, and there and to the west on the headwaters of Cherokee Creek and Dry Fork it attains its maximum thickness in this quadrangle. Further descriptions and an analysis of it are given in connection with the mention of its occurrence on Cherokee Creek (p. 103). At the headwaters of Cat Creek it has not been developed on a commercial scale, owing to remoteness from transportation. The extent of its outcrop in this locality is limited, as the northward dips carry it below drainage level near the mouth of Thompson Fork. On the map its outcrop line in the valley of Cat Creek is practically coincident with the red line which indicates the horizon of the Vanport limestone and its clay. It has been opened by Andrew

[a] Report on the eastern coal field: Kentucky Geol. Survey, vol. C, p. 19, 1884, pl. 1.

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Webb, Andrew Cooksey, and W. H. Moore, and at Moore's bank the following section was measured:

Section of Cat Creek coal bed at bank of W. H. Moore.

	Inches.
Shale, black.	
Coal	1½
Bone	4½
Coal	17½
Bone	½
Coal	24
	48

A thickness of 4 feet 10 inches to 5 feet is reported from other country banks in the immediate vicinity. In some places, at least, this coal is sufficiently thick and free from impurities to make it valuable, but in other places it is so badly split up by impure partings that it will have little value except for country trade. The following two sections illustrate this impure phase:

Sections of Cat Creek coal bed.

	Inches.
Shale, black, containing small stringers of coal	1
Coal	1½
Shale, black	4
Coal	5
Shale, black	12
Coal and shale	4
Coal	4½
Bone	1
Coal	9
	42
Shale, black.	
Coal	4
Shale, black	19
Coal	2
Bone	1
Coal	1
Bone	½
Coal	8
Bone or coal	½
Coal	1½
Clay.	
	37½

The fact that it has a good section on Cat Creek and shows well on Cherokee Creek is sufficient evidence that this coal bed is well worth careful attention. It should be prospected with a diamond drill in the intermediate territory before actual operations on it are begun.

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Character.—The Cat Creek coal is of excellent quality and when not badly split up gives much satisfaction as a domestic fuel, being hauled many miles into the surrounding country.

POTTSVILLE COALS.

LICK CREEK (NO. 4).

Extent and development.—The highest coal in the Pottsville is from 55 to 75 feet above the Torchlight bed. It is locally known as the "5-foot vein" but is sometimes called the "Big vein" and probably corresponds with coal No. 4 of the Kentucky Survey. Its maximum development is in the hills east of Lick Creek and between Lick Creek and Levisa Fork, and it may be conveniently designated, therefore, the Lick Creek coal. From the fact that it overlies the Torchlight bed it occurs over a smaller territory above drainage level, and is not found as far south in the hills as the Torchlight. Though locally thicker than the coal below, it will probably not be found so persistent and uniform. It has been prospected by the Torchlight Coal Company between Threemile Creek and Levisa Fork, where it proves to be of workable thickness, and in this region it is about 60 feet above the Torchlight bed. East of Threemile Creek, prospects have been opened on it on Donithon Branch, where it is also workable. In West Virginia the coal at this horizon does not appear to be of workable thickness; at least no openings were observed on it. West of Lick Creek the horizon is marked by a coal bloom or smut, but in no place has it been found sufficiently thick to work profitably except for local purposes. It has been worked for family use at one or two points on San Branch near Irad and also one-fourth of a mile below the point where Little Blaine Creek enters Big Blaine. So far as known the coal has never been worked on a commercial scale in Big Sandy Valley. In this district the most promising field in which to prospect for this coal is in the hills along Levisa and Tug forks, south of Torchlight.

Character.—Sections obtained from this bed are shown in fig. 5. The section obtained at the head of Lower Gavitt Creek on the property of the Torchlight Coal Company differs strikingly from the remaining three, obtained from test drifts of the Louisa Coal Company in the hills between Lick Creek and Levisa Fork, just west of Torchlight. The upper 20 inches of the coal on Lower Gavitt Creek appear to be much broken up. The lower benches, which average about 19 or 20 inches, are separated by a small clay parting. In places the upper bench consists of clean coal, giving the three benches as in the Torchlight bed. The coal is also reported with three benches on the headwaters of Donithon Creek, but here the upper bench is slightly thicker than either of the two lower. The section

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C. M. Weld for the Torchlight Coal Co
r as follows:

Lick Creek coal bed at the head of Ox Hollow, Do

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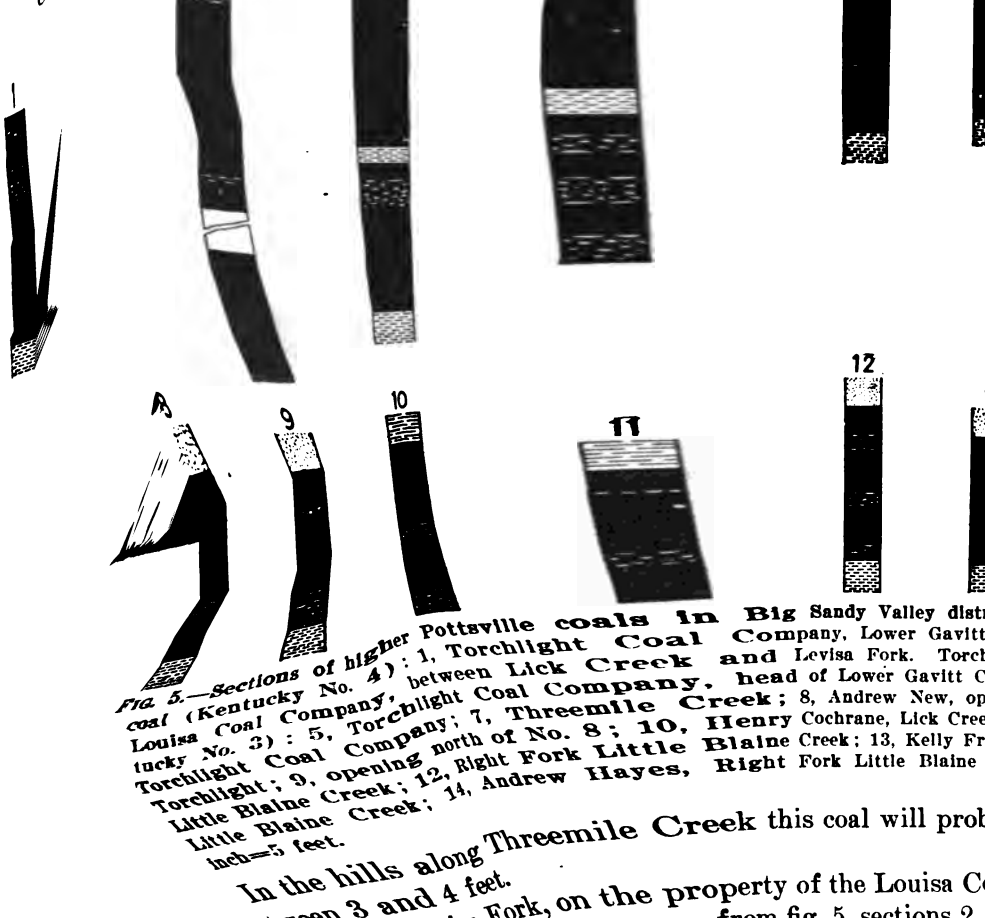

Fig. 5.—Sections of higher Pottsville coals in Big Sandy Valley distr
coal (Kentucky No. 4): 1, Torchlight Coal Company, Lower Gavitt
Louisa Coal Company, between Lick Creek and Levisa Fork. Torch
tucky No. 3): 5, Torchlight Coal Company; 7, Threemile Creek; 8, Andrew New, op
Torchlight; 9, opening north of No. 8; 10, Henry Cochrane, Lick Cree
Little Blaine Creek; 12, Right Fork Little Blaine Creek; 13, Kelly Fr
Little Blaine Creek; 14, Andrew Hayes, Right Fork Little Blaine
inch=5 feet.

In the hills along Threemile Creek this coal will prob
between 3 and 4 feet.

West of Levisa Fork, on the property of the Louisa C
this coal thickens, as will be seen from fig. 5, sections 2,
general the coal in this vicinity is irregular, but consis
served, of two main benches separated by a clay par
from a few inches to 5 feet. The coal south of the pr
this company is reputed to be very irregular and of poo
these statements can not be corroborated by the writer,

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seen of it at any point. West of Lick Creek, about one-half mile above the mouth of Rhubens Branch, the coal measures about 2 feet on the outcrop in a well-exposed section showing the top of the Pottsville and the Allegheny, as follows:

Section on Rhubens Branch.

Hilltop.	Ft.	In.
Shale, red	30	
Sandstone	20	
Shale, red	20–25	
Bench.		
Sandstone, shaly	18	
Shale, sandy	16	
Sandstone, shaly	6	
Shale, light olive	7	
Clay, white	1	
Soil, ferruginous clayey	30	
Shale, sandy	9	
Sandstone, coarse, yellow, massive	15	
Shale	10	
Clay	5	
Shale	5	
Clay with iron-ore nodules	5	
Shale, black (coal?)		2–3
Shale, gray	10	
Coal		2
Shale, drab	7	
Shale, purple	5	
Sandstone	8	
Coal No. 5		12
Sandstone, laminated	15	
Coal No. 4 (Lick Creek coal)		24
Sandstone, massive	25±	
Coal No. 3.		
Sandstone, massive.		

This section indicates the erratic character of the Allegheny and shows how difficult it is to locate its exact upper boundary.

The massive sandstone at Busseyville marks the top of the Pottsville formation. This sandstone rises in the direction of the forks of Little Blaine Creek, and a short distance below the residence of L. D. Pigg the coal appears above drainage level and has been opened about 15 feet above the road to the left. A short distance beyond the same coal shows a section as follows at F. R. Bussey's bank:

Section of coal bed at F. R. Bussey's bank, near Busseyville.

Sandstone, massive.	Inches.
Coal and black shale	30
Sandstone lentils, sometimes absent	2
Shale and bone	10
Coal	5
Shale, drab fissile	22
Coal	15
Bone	1

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	Inches.
Coal	2
Bone	2
Coal	15+

About 60 feet below this coal, at road level, is the bloom of another and lower coal, which has been opened by L. D. Pigg in the hill to the west. This coal has a section as follows:

Section of coal bed opened by L. D. Pigg near Busseyville.

	Inches.
Limonite, nodular	4
Shale	19
Bone	3
Coal	4
Shale	19
Bone	4
Coal	7

These coals are believed to be above the true Torchlight coal, which shows as a bloom at the road corner at the confluence of Left and Right forks of Little Blaine Creek. It is possible that one of these two beds represents the Lick Creek coal and that the other may represent a new bed in the section. It is also possible that these coals may represent the two benches of the Lick Creek coal, the parting of 5 feet of clay in the region east of Lick Creek having expanded to 60 feet farther west. The data on this point are not sufficient to make it absolutely certain that these two beds represent the two benches of the Lick Creek bed, but the writer is inclined to this view. Neither of the two coals, where seen outcropping, is of commercial importance.

Where the Lick Creek coal is of workable thickness it is of a bright, hard, bituminous variety, with occasional bands of splint or semi-cannel coal. The upper of the two lower benches appears to be the more uniform, but in places the lower may probably be worked with it. Locally, however, it is badly split by bony partings. At many points between Levisa Fork and Tug Fork all three benches may be worked if sufficient care is exercised in separating the clay and bone partings. As a rule the roof of this coal is formed by shale, but in some places the base of the massive Homewood sandstone extends down practically to its top. The following analyses indicate the character of this coal:

Analyses of Lick Creek coal.

	1.	2.
Moisture	6.00	0.97
Volatile matter	32.40	32.70
Fixed carbon	57.40	55.69
Ash	4.20	9.58
Sulphur	.049	1.05

1. Furnished by J. H. Northup, of Louisa, Ky., from a sample collected at the head of Donithon Creek.

2. Furnished by A. C. Collins, of the Louisa Coal Company. Otto Wuth, analyst. Sulphur is included in the total.

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The foregoing analyses show a good coal of the bituminous grade, corresponding favorably with much of the Pittsburg coal of western Pennsylvania. It contains a rather higher percentage of volatile matter and correspondingly lower fixed carbon. On account of its hard and somewhat splinty character it will bear transportation and stocking well. It is doubtful whether it will prove to be a good coking coal, but experiments with regard to this point have not been made.

TORCHLIGHT COAL (NO. 3).

Name.—The next lower workable coal in the Pottsville group is perhaps the most important of all the beds thus far developed on the upper waters of Big Sandy River and its tributaries in this quadrangle. In the Kentucky reports this coal is known as No. 3, or McHenry coal, the latter being the name of the property on which the coal was first worked on any marked scale. In this description it will be referred to as the Torchlight bed, from the fact that the Torchlight Coal Company has worked it more extensively than any other company at Torchlight, on the Chesapeake and Ohio Railway 6 miles south of Louisa, and opposite the old McHenry property on the west side of Levisa Fork. It is locally known also as the "Check House vein." It corresponds to the Lower Mercer coal of Pennsylvania.

Extent.—The Torchlight coal first appears above drainage level on Threemile Creek near the Threemile schoolhouse, and is reported on Levisa Fork near the bed of the creek just north of the railroad bridge at Walbridge. It is probably present in all the hills south of these points in the territory included between Tug and Levisa forks and also in West Virginia. East of Threemile Creek, however, it does not seem to have been extensively prospected and little seems to be known about it. In the hills between Threemile Creek and Levisa Fork it has been fairly well prospected, and this is also true of the territory lying between Levisa Fork and Lick Creek to the west. It is present in the hills along Left and Right forks of Little Blaine Creek, but owing to northward dips disappears below drainage level a short distance north of the confluence of these two forks. A reference to the map (Pl. I) will show the outcrop of this bed so far as it is known to be of workable thickness.

Development.—This coal was first opened at McHenry's bank, on the west side of Levisa Fork opposite Torchlight. Since then it has been developed on a commercial scale by the Torchlight Coal Company at Torchlight. During the summer of 1905 the mine was closed, but it started up again in the following spring. In the hills west of Levisa Fork this coal has been faced in several places by the Louisa Coal Company to ascertain its possibilities. It has also

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been opened by Andrew New and others northwest of Torchlight. On Lick Creek several small country banks have been opened and a small amount of coal has been removed for the country trade by Richard Childers, Henry Cochrane, and others. On Left Fork of Little Blaine Creek this coal appears to have a section similar to that in the region about Torchlight. It has been opened at a few places along this creek a short distance south of its confluence with Right Fork.

Along the pike east of Adams it is found well up in the hills on the south side of the creek and near road level on the north side, owing to the steep dips. It has been opened in this region by Kelly Frailey, Andy Hayes, and others. It is possible that the coal opened by James Adams west of Adams corresponds to the Torchlight bed.

Character.—Ten sections of the Torchlight coal are represented in fig. 5. It will be seen from these sections that the coal bed is somewhat variable. In places it occurs as a single bench, as at the bank of Richard Childers, on Lick Creek, where 37 inches of clean coal were measured, but usually it consists of two or three benches. As a rule a clay parting separates the top benches. This clay parting is in general of knife-edge thinness (sections 5, 6, 8, 9, 11, fig. 5), and is, perhaps, entirely cut out in some places, as at the Henry Cochrane and Kelly Frailey banks (sections 10, 13, fig. 5), on Right Fork of Little Blaine Creek. It rarely attains a thickness of an inch, though in exceptional cases it may exceed this measurement, as at an opening of the Torchlight Coal Company on Threemile Creek, where a parting of 3 inches was measured (section 7, fig. 5). The third or lowest bench ranges from less than 6½ to over 14 inches in thickness. It is separated from the middle bench by a persistent bone parting averaging 3 to 4 inches.

The coal in this bed is of both the splinty and the soft bituminous varieties. The top bench above the clay parting is usually soft; the middle bench, though generally of soft, lustrous bituminous coal, in many places contains hard, splinty layers and is therefore slightly harder. The lowest bench is as a rule of hard, dull, splinty coal, and serves as an excellent base for pillars in mine working. This bench is also drilled before shooting. In mining, all three benches may be worked and the bone or "niggerhead" between the two lower benches removed by hand picking. The roof of the coal bed varies. It is in some places shale and in others massive sandstone. The shale, where present, ranges in thickness from a few feet up to 15 feet, more or less, and sometimes gives much trouble in mining. The roof of the coal, where it is composed of shale, has to be carefully watched and rather heavily timbered to avoid falling and "creeping." On this account mining with a shale roof is attended with more danger and expense than where the coal is overlain by sand-

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stone. Above the layer of shale there is usually a very massive sandstone of varying thickness, which serves as one means of identifying this bed.

Below the lowermost worked bench there are in many places one or two smaller benches of coal separated from the main bed by a fire clay or bone parting (sections 6 and 7, fig. 5). These are never mined. The true floor of the coal, as a rule, is clay. A few analyses of this coal are as follows:

Analyses of Torchlight coal.

	1.	2.	3.	4.	5.
Moisture	4.60	2.86	2.10	1.90	1.23
Volatile matter	35.70	37.49	35.95	35.47	35.82
Fixed carbon	53.28	40.85	37.79	35.86	53.37
Ash	6.42	18.80	24.16	26.27	8.40
Sulphur	1.08	1.11	1.77	1.22	1.18

1. Sample from McHenry's coal bank, Lawrence County, Ky. Report on the eastern coal field: Kentucky Geol. Survey, vol. C, p. 18. Robert Peter and Mr. Talbut, analysts.
2. Torchlight Coal Company's mine, second entry. Ricketts & Banks, analysts.
3. Torchlight Coal Company's property on Lower Gavitt Creek. Ricketts & Banks, analysts.
4. Torchlight Coal Company, Fivemile Shoal. Ricketts & Banks, analysts.
5. Crop coal from hill between Levisa Fork and Lick Creek property of the Louisa Coal Company. Otto Wuth, analyst. Sulphur is included in the total.

From these analyses it will be seen that the volatile matter averages about 35 per cent and the fixed carbon approximately 45 per cent. The ash and sulphur are comparatively high, especially in the samples analyzed by Ricketts & Banks for the Torchlight Coal Company. The lower and dirty benches were probably included in the samples analyzed by this firm, but in the mining of the three upper benches this material would probably serve as a floor; or, if it were found necessary to remove it, it could be picked out and gobbed, and the main and clean benches shot down from above. The main benches would yield from 2½ to 4 feet of fairly clean coal; on an average, perhaps about 3 feet. With this figure as an average, the yield per acre may be conservatively placed at 3,500 tons. From the sections of the coal given in fig. 5, it will be seen that the danger of introducing unduly large amounts of ash into this coal during the course of actual mining is very great, and the amounts of ash represented in analyses 1 and 5 are perhaps below what would be found in practice. If the entire bed—that is, the three main top benches—is to be mined and successfully marketed, pains must be taken to eliminate the bone and clay where they are of abnormal thickness. This may be accomplished either by hand picking—a slow, tedious method and one which in the hands of miners is liable to lead to injury both to the reputation of the company and to the coal—or by washing. The expense of the latter operation ought not to exceed from 5 to 7 cents per resulting ton of coal. In no case would it appear advisable to mine any coal below the lower splint band.

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LOWER COALS.

Extent.—The lowest coals developed in this district are those nearest its southern edge, as the rise of the beds to the south brings up successively lower horizons toward the southern edge of the quadrangle. Certainly the lowest exposed coal beds in the entire quadrangle occur in the section southwest of Gallup. As will be seen from the section of the Pottsville formation on pages 38–39, and from the sections on Pl. IV (p. 28), four small coals are found below the Sharon sandstone. None of these coals has ever been worked in this quadrangle, though one of them measures 24 inches at one point. Between the Sharon and the next massive sandstone above is about 50 feet of shale with two small coal beds. The highest of these coals has been worked near a sharp bend in the railroad track south of Torchlight. Where measured on the outcrop this coal is 16 inches thick. The sandstone above it was formerly, though probably erroneously, correlated with the Sharon sandstone seen on Everman Creek. About 2 miles south of Torchlight there is at this horizon 100 feet of almost continuous sandy beds with two slight breaks near the middle. Above this massive member are several small coal beds in an interval of 30 to 35 feet. A detailed section of this group of coals, measured near the mouth of Lower Gavitt Creek, below Torchlight, is as follows:

Section of coals at the mouth of Lower Gavitt Creek, Lawrence County, Ky.

	Ft.	In.
Shale, black, and clay	2	2
Coal	1	7
Parting, "Little Cannel"		½
Coal		2
Sandstone, laminated	10	
Coal	1	
Shale, sandy, or fire clay	2–3	8
Coal	2	5
Shale	2	5
Coal		3
Shale, drab to dark	2	
Coal	1	8
Shale, black, and fire clay	2	3
Slate, black, and bone.		
Fire clay	3	
Bed of creek.		

The uppermost of these coals is workable over a considerable area in the southeast corner of the quadrangle and may be looked for at a distance of about 140 feet below the Torchlight coal. It is present in the hills along Levisa Fork and Threemile Creek, gradually rising

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from railroad level at the mouth of Lower Gavitt Creek, just below Torchlight station. West of Levisa Fork this coal appears above drainage level near the head of Lick Creek, the group of coal blooms in which the "Little Cannel" belongs appearing near the summit of the ridge in the road at the head of Lick Creek. The character of the coal in this vicinity could not be determined, owing to the fact that it has not been opened, but west of the Left Fork of Little Blaine it has been opened in a few places near the level of the creek and is of workable thickness, though badly split up by bone and fire-clay partings.

On Right Fork of Little Blaine the lithologic succession is not so characteristic as to the eastward. Near Adams a massive sandstone appears above the bed of the creek and rises gradually to the south up the creek. On the hill southeast of Adams a distinct coal blossom may be seen close to the top of this sandstone with the shale above it. The sandstone underlying this coal may be traced with hardly a break up the creek, and about three-fourths of a mile south of Adams the coal directly above it is worked. Instead of being overlain by shale, as at Adams, it is now capped by a very massive sandstone, and the coal, as nearly as can be estimated, is about 110 feet below the Torchlight bed, and is regarded tentatively as of the "Little Cannel" group, though it may be higher.

Development.—The "Little Cannel" coal has been opened near the head of Threemile Creek and at one time was mined and shipped from this locality over the old Chatteroi Railroad. About 5,000 tons are reported to have been shipped before the road's alignment was changed to its present location along Levisa Fork. Operations ceased as a result of the financial panic in 1893, and since then nothing on a commercial scale has been attempted.

A short distance south of Torchlight the coal has been worked on a small scale and a few hundred tons have been removed, under lease from the Torchlight Coal Company. There are small openings north of the station and in the hills on the west side of the fork. Developments on Left and Right forks of Little Blaine Creek are of local importance only and supply the country trade. Though this coal is above drainage level along the headwaters of Rich Creek, it does not seem to be of sufficient thickness to justify opening it on even a small scale.

Character.—This bed of coal is known as the "Little Cannel" bed about Torchlight for the reason that it contains near the middle of its upper bench a thin band of coal with enough volatile matter to place it among the cannel coals. Sections obtained near Torchlight (sections 1 and 2, fig. 6) show this coal to vary from a thickness of 19½ inches north of the tipple to 2 or 2½ feet south of the tipple of the Torchlight Coal Company. This coal is split into two benches with a part-

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ing of one-half to 1 inch of clay near the bottom. The cannel layer is not shown in the sections given in fig. 6, but occurs near the middle of the upper bench and ranges from 3 to 6 inches in thickness. It resembles splint coal rather than true cannel. Perhaps the chief value of this bed in the future will result from this band of cannel. Four inches of cannel to 2 feet of coal may be taken as a conservative average of the two grades of coal in this bed. On this basis it comprises one-sixth of the total coal and would yield about 483 tons per acre, assuming the specific gravity of 1.194 determined by Mr. Hislop. It separates fairly readily from the bituminous coal above and below and breaks out in large blocks.

The coal, as a whole, is moderately lustrous, with yellowish brown streaks. The cleavage is laminated with cross fracture, angular to

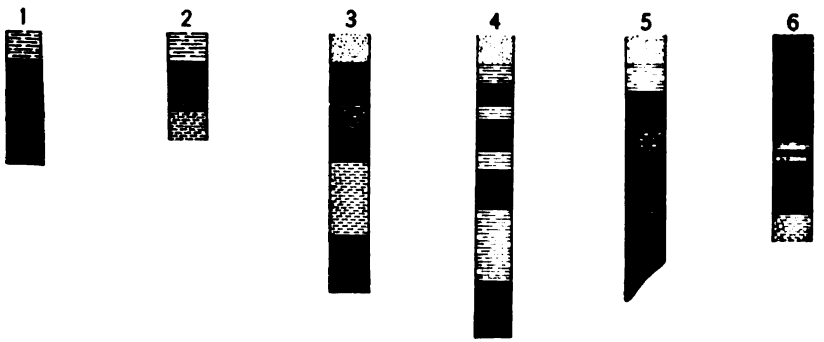

FIG. 6.—Sections of lower Pottsville coals in Big Sandy district. 1, "Little Cannel" coal, north of Torchlight; 2, "Little Cannel" coal, south of Torchlight; 3, Hiram Blackburn, Left Fork Little Blaine Creek; 4, John R. Pack, Right Fork Little Blaine Creek; 5, Mary Hayes, Right Fork Little Blaine Creek; 6, E. G. McInster, Right Fork Little Blaine Creek. Scale, 1 inch = 5 feet.

subconchoidal. On the fire it intumesces and agglomerates. Analyses are as follows:

Analyses of "Little Cannel" coal from Levisa Fork.

	1.	2.
Water	2.25	2.70
Volatile matter	54.95	45.61
Fixed carbon	39.35	47.17
Ash	2.95	3.90
Sulphur	.50	.62

1. Department of mines and metallurgy, World's Columbian Exposition, analyst.
2. George R. Hislop, Paisley Gas Works, analyst.

George R. Hislop, of the Paisley Gas Works, who has made a rather exhaustive test of this coal and has also studied the resulting gases, reports that "this is an excellent cannel coal. It is easily distilled, yields a large volume of 34.20 candle gas, and affords at the

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same time 10.25 hundredweight per ton of excellent residual coke. The foul gas contains a moderate percentage of impurities. Compared with main Lesmahagow cannel coal taken as 100, calculated on the basis of 13,000 cubic feet of gas and 1,535.5 pounds of sperm per ton, and having regard for the secondary products and the cost of purification of the gas, this coal is equal to 107.48."[a]

TRANSPORTATION FACILITIES.

Transportation facilities in the Big Sandy Valley district are furnished at present by the Chesapeake and Ohio Railway along Levisa Fork in Kentucky and by the recently completed Norfolk and Western Railway along Tug Fork in West Virginia. The line of the Chesapeake and Ohio Railway was formerly up Threemile Creek after crossing Levisa Fork at Walbridge, and the roadbed of this old line, from which the steel was removed about fifteen years ago, is still in fair condition for a spur track from the main line at Walbridge, should the developments on Threemile Creek warrant its construction. In addition much of the Big Sandy region is readily accessible by water. The improvements along the river projected by the Federal Government, which are now partly completed, are expected to provide navigable depths many miles south of the limits of this quadrangle and to provide a navigable season through the entire year instead of six months, which is now the average. The facilities for cheap transportation that will be offered when these improvements are completed are so obvious as to need no comment here.[b]

CHESAPEAKE AND OHIO RAILWAY DISTRICT.

EXTENT.

The district tributary to the Chesapeake and Ohio Railway includes nearly the whole of Boyd County, together with small parts of Greenup, Carter, and Lawrence counties, Ky. Its eastern boundary has already been described as the ridge separating the waters of Big Sandy and East Fork. The ridge separating the waters of Little Sandy River and East Fork of Little Sandy has been chosen as its western boundary. On the south it is limited by the ridge south of Straight Creek and the headwaters of East Fork. This district includes all the operations along the Ashland Coal and Iron Railway as far south as Straight Creek.

[a] Compare other cannel coals on pp. 88–92.

[b] See Survey of Big Sandy River, West Virginia and Kentucky, including Levisa and Tug Forks: House Doc. No. 326, 56th Cong., 1st sess.

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GEOLOGY.

The rocks in this district are comprised in the Pottsville, Allegheny, and Conemaugh formations. The highest beds belong to the Conemaugh. This formation is not represented in its entirety at any point west of Big Sandy River, so far as known. The eastward dips which cause the lower beds to cover most of the surface west of the Ashland Coal and Iron Railway bring the Conemaugh beds lower and lower in the hills toward Big Sandy River. They are the only surface rocks in the southeastern part of this district, where they have a thickness of 300 to 400 feet. At the base of this formation is a rather massive sandstone, well shown west of Alley in the hills bordering Pigeonroost Creek. Above the sandstone, at varying distances, but rarely exceeding 40 feet and usually less, occurs a fossiliferous limestone, one of the Cambridge beds, which is closely overlain by another massive sandstone. Thus the lower hundred feet of the formation is usually sandy and is accordingly comparable with the lower part of the Conemaugh at the mouth of Big Sandy River. Though here and there the upper part of the formation contains massive sandstone, it is shaly for the most part, the shales being reddish and purplish, with local green layers. Many of these shaly members would be of value were they situated near lines of transportation. No commercial coals are known in this formation.

The Allegheny formation in this district has a thickness averaging from nearly 180 to 200 feet. The general section (Pl. IV, p. 28) illustrates well the number and relations of the coal and clay beds in this formation. About Ashland its basal portion is very sandy and comparable with the lower part of the Allegheny in Ohio. (See section, pp. 30–31.) Farther south the massive phase of the sandstone, at least above the Winslow coal bed, seems to change to a more thinly bedded or shaly sandstone, the remainder of the interval between the Winslow and Coalton coals being shaly. The Coalton coal is usually overlain by a massive sandstone above which is a thin red or purple shale bed, well exposed on the county road east of Summit. From the top of the sandstone overlying the Coalton coal to the base of the Mahoning sandstone the beds are prevailingly shaly in character, and include the Hatcher and Zelda coal beds.

The materials of most economic importance in this group of rocks are coal, fire clay, and iron ore. In most places the valuable coal beds are confined to the lower half of the formation, but in a few localities the higher coals are workable. Not more than three distinct workable coal beds were seen, and in most places only two coals are of workable thickness. A valuable bed of fire clay occurs well toward the base of the formation associated with the Vanport ("Hanging

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Rock") limestone, and this limestone is overlain in many places by a bed of iron ore, which in the early seventies was greatly esteemed and extensively mined by stripping. Between the Winslow and Coalton coal beds, about 20 to 25 feet above the latter, is found a kidney iron ore which about thirty years ago was worked to some extent, and about 25 feet above the Coalton coal is another horizon of kidney ore.

In a general way the rocks of this formation cover the surface of the district in a zone conforming in trend with the structure contours—that is, northeast and southwest. West of the Ashland Coal and Iron Railway the Allegheny is present in the tops of the hills, but east of the railroad the dips cause the formation to occupy a lower and lower position in the hills and to disappear well up toward the head of East Fork and Straight Creek. In the northwestern part of the district they cover most of the surface, but in the southeastern part they are entirely below drainage level.

The lowest beds in this district are exposed along East Fork of Little Sandy River, in the northwestern part of the district. Here are Pottsville rocks at least 260 feet thick. To the east, approaching the center of the basin, the Pottsville gradually descends below drainage level, and except along Ohio River the territory covered by it east of the Ashland Coal and Iron Railway is very small. West of the Ashland Coal and Iron Railway, in the hills dividing Little Sandy from East Fork the Pottsville reaches well up to the hilltops, and its rocks are conspicuous on the surface. The formation is prevailingly sandy, but perhaps not quite so much as in the region along Tug and Levisa forks. The top member, the Homewood sandstone, maintains its usual prominence in most parts of this district. Along Ohio River near Ashland, and to the southeast, near Cliffside Park, this member is unusually massive, attaining in some places a thickness of 75 feet. It is a question whether all this sandstone is really of Homewood age, for west of Ashland it apparently forms one massive cliff reaching to the base of the fire clay at the horizon of the Vanport ("Hanging Rock") limestone. It is quite possible, therefore, that the upper part of this member may be of Allegheny and not Pottsville age. Though the Homewood sandstone in this district is generally massive, south of Princess and near Coalton and Rush it dwindles to a shaly sandstone, never exceeding and rarely reaching a thickness of 10 feet. Taken as a whole, it is, however, the most prominent bed in the Pottsville in this district. The underlying beds are prevailingly sandy, chiefly sandy shales and shaly sandstones, becoming in places prominent cliff makers.

The number of coal beds in these rocks is not definitely known. It is probable that there are more than have heretofore been recognized. Near Princess tunnel, for instance, a section was measured from the road corner near the store of the Princess Land and Mining Company

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to the highest exposed rock above the tunnel, and in this section four coal beds showed within a distance of 70 feet below the top of the Homewood sandstone. On the road ascending the hill, a few rods northwest, G. H. Ashley measured another section to the top of the hill, which showed the coal beds at the top of the Pottsville and also some of those in the Allegheny. This section is as follows:

Section near Princess tunnel.

Top of hill.	Ft.	In.
Sandstone, shaly	8	
Sandstone, shaly, calcareous	2	
Shale, olive	6	
Sandstone, hard	2	
Shale, olive	6	
Streak of dark shale.		
Clay, drab	2	
Iron ore	1	
Shale, olive	6	
Coal (No. 8)		2+
Clay, light drab	2	
Shale, olive, and sandstone	12	
Shale, olive	12	
Iron-ore nodules		8
Clay, drab, or shale	4	
Sandstone, olive, shaly	7	
Coal (No. 7)	1	3
Shale, drab	3	
Shale, sandy, and shaly sandstone	15	
Iron ore, red		6
Shale, olive	5	
Sandstone, hard massive	15	
Coal	1	9
Clay, drab	3	
Coal		½
Clay, drab flint		6
Clay, black carbonaceous flint		0–2
Clay, light drab, sandy at base	7	
Sandstone, green and white, fine-grained (Home-wood—top of Pottsville)	8	
Shale, olive, and fire clay	4	
Iron ore		6
Shale, drab	6	
Coal		5
Clay		2
Coal		5
Clay, light drab	3	
Shale, dark drab		6
Clay, dark drab to black	1	
Clay, drab	2	
Sandstone, thin-bedded, shaly	12	
Shale, sandy	5	
Coal		1½

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	Ft.	in.
Shale, reddish brown		1–4
Coal		2
Flinty lentil		0–2
Coal	1	
Clay		9
Coal		6
Fire clay, light drab, sandy	4	
Coal		5
Clay		1
Coal		3
Shale, sandy and drab fire clay	6	
Shale, sandy	12	
Sandstone	15	

The following section, compiled from barometric measurements along the northern edge of the area from Argillite eastward to Hood Creek, gives a general idea of the character of the Pottsville rocks and shows also the position of the workable coals:

Section from Argillite to Hood Creek.

	Ft.	in.
Sandstone, Homewood	30	
Coal, workable in places.		
Sandstone, shaly	20–40	
Coal.		
Sandstone	6	
Coal		2–3
Sandstone	6	
Coal (No. 3), workable in places.		
Sandstone, massive	10	
Concealed	15±	
Coal		5
Fire clay	4	8
Shale and massive sandstone	35	
Coal, workable.		
Probably sandy	50	
Coal		4
Sandstone, shaly	20	
Concealed	10	
Shale, black, and fire clay	10	
Concealed	10±	
Sandstone, massive	10	
Concealed	10±	
Sandstone, massive	10	

On Catletts Creek and in the eastern part of Ashland there is an important bed of fire clay underlying the Homewood sandstone. Formerly the iron ore in this formation in this district was of considerable economic importance, notably the bed occurring 30 to 40 feet above the Danleyton coal, called by P. N. Moore "the main block ore."[a] None of the beds of iron ore of this formation are now worked.

[a] Report on the eastern coal field: Kentucky Geol. Survey, vol. C, 1884, pp. 133–138.

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THE COALS.

ALLEGHENY COALS.

UPPER COALS.

The highest coal bed that has been worked in this district corresponds with coal No. 9 or the Upper Freeport coal of the Ohio section and with the Zelda coal in the Big Sandy Valley. It is not of sufficient thickness to be of any practical importance. It has been opened by Albert Baldridge near the mouth of Garner Creek and is reported to be 18 to 20 inches thick. In the road 20 feet below is the bloom of a lower bed, probably the Hatcher coal, which is not of workable thickness here.

COALTON COAL (NO. 7).

Name.—The highest important bed in this district is the Coalton coal, or No. 7 of the Kentucky reports, known also as the Sheridan and as the Ashland[a] coal, though the latter term is not used much in northeastern Kentucky. In southern Ohio this is considered the most important of all the coal beds and is known under a variety of names, according to the location where it is developed, and shows a commercial thickness. Its most common names are derived from the mining centers Nelsonville and Straitsville, along the Marietta and Cincinnati Railroad. It is also known as the Carbondale or Mineral City coal, and in Gallia and Lawrence counties the name Sheridan is applied. The name Coalton will be used in this report, for it was mined originally at Coalton and was widely known under the name of Coalton coal.

Geologic position.—The Coalton coal lies at about the middle of the Allegheny formation. As it is the highest workable coal in nearly all of the district under consideration, no great difficulty should be experienced in identifying it. It lies in most places about 35 to 45 feet above the next lower bed, the Winslow coal or No. 6 of the Kentucky Survey, and from 40 to 60 feet below the next higher or Hatcher coal, No. 8 of the Kentucky series. It will be found about 100 feet above the top of the Homewood sandstone where the Allegheny formation is normally developed and about the same distance below the base of the Mahoning sandstone. Below it at a distance of 25 feet and above it at almost the same distance there are two persistent bands of kidney ore, the lower known as the yellow kidney and the upper as the red kidney ore. These ore beds have long been used as datum planes from which to determine the position of this coal, as they are among the most persistent and reliable ore horizons in this region.

[a] Ohio Geol. Survey, vol. 3, pt. 1, 1878, p. 918.

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Extent.—The outcrop of the coal will be seen from the economic map (Pl. I). Its zone is about 10 miles wide in the northern part of the district and follows the structure lines to the southwest, gradually tapering as it approaches Willard and Webbville. The rise of the beds southward and beyond these towns soon carries this bed above the hilltops. It is present in all the hills bordering Williams Creek and its tributaries, Straight Creek, and East Fork and its branches, southeast of Naples. In the Flatwoods area south of Ashland the hills do not rise quite high enough to catch it. Though present on Catletts Creek and Keyes Creek, it is doubtful whether it is so thick as in the region farther west. Its horizon is also believed to be above drainage level on Chadwick Creek. On Garner Creek it has been opened at a few country banks.

In general the western limits of the Coalton coal outcrop coincide with the boundary between Boyd and Greenup counties, and south of Greenup County follow the divide between Little Sandy River and East Fork. The points on the various creeks where it descends below drainage level toward the center of the basin are plainly shown on Pl. I.

Development.—It may be stated that over nearly all of this district where any body of the Coalton coal is found in the hills it has either been prospected or worked. Southwest of Ashland in the hills bordering Hood Creek it is prospected 40 to 50 feet above the Winslow coal. Near Winslow and Summit it has been opened on many farms, but very few of the prospects were in good condition in the summer of 1905, while the reverse was true of the underlying Winslow. In many places the two beds had been opened on the same hillside, but the higher coal had usually been abandoned first. This fact may be explained in either of two ways. The average country bank is worked for a short time, and when the workings extend far into the hill and the expense of timbering increases, as well as the danger from the roof, the farmer, unless he has an experienced miner digging for him, will abandon his bank and open in another place. Another explanation is that the lower of the two coals immediately southwest of Ashland may be superior for domestic purposes. It is a fact that on many of the farms there is only one opening on each of these two coal beds and only the lower coal is worked. At Winslow, above the Ashland Coal and Mining Company's No. 8 mine on the Winslow coal, the upper or Coalton bed was opened but afterward abandoned. It is reported as too "pockety" to be worked with profit.

This coal bed has been opened at many points on Shope Creek near Clinton furnace. It disappears below drainage level at the point where the Catletts Creek road joins the Shope Creek road. Along East Fork of Little Sandy it has been opened on numerous

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farms about Mavity and Cannonsburg. On Garner, Pigeonroost, Fourmile, and both branches of Trace Creek, and, in fact, on all the creeks flowing into East Fork, east of the Chesapeake and Ohio Railway and north of Garner and Alley, many openings have been made on this bed.

The commercial operations naturally have been confined to the territory lying close to the Chesapeake and Ohio Railway. With the exception of a little work done by the Ashland Iron and Mining Company at Winslow, now abandoned, operations on this bed begin at Princess and extend as far to the south as Willard. The names of companies working the coal at present are given on the margin of the economic map (Pl. I). With a few exceptions the operations are mostly on a small scale. The most important group of mines are those belonging to the Ashland Iron and Mining Company, situated near Rush, in both Boyd and Carter counties. Some of these are worked by the company and others are worked under lease. The Straight Creek Mining Company is another large producer, as are also the Princess Land and Mining Company, the Eastern Kentucky Railroad, John Wurts, and the Adkins Coal Company. The remaining operations are small and at the time of the writer's visit in 1905 some of them were closed. In some of the mines pillars were being drawn, indicating a nearly exhausted condition. The mines along the Chesapeake and Ohio Railway from Princess to Rush have been worked many years and large quantities of coal have been shipped. Most of the coal above drainage level and conveniently situated for exploitation has been removed, and the present operations are largely remnants of what were once very much larger and important mines. In some of the hills the coal is reported as completely exhausted.

Physical aspects.—A series of 25 sections (fig. 7) of the coal bed in this district will give a fair idea of the thickness of this bed. It will be observed that the coal occurs usually in either two or three benches, but in a few places, as at the mines of the Ashland Iron and Mining Company on Rush Creek, four benches were observed (section 10). Most of the measurements made in this district and to the southwest about Willard, Carter County, indicate that more commonly there are three benches. These benches are separated by bone or clay partings. The upper parting generally ranges from 1 to 5 inches and rarely exceeds 1 foot in thickness. In most places the lower parting is bone from one-half inch to 2 inches thick. About Rush this parting is clayey in character and thin. On Mile Branch the thin clay stratum observed above the two benches is of interest as pointing to conditions of deposition similar to those observed elsewhere, but changing after this clay was deposited, with the result that shale was laid down instead of coal.

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As a general rule the upper bench is not mined. This is due to two or more causes—first, this bench is variable in thickness, and, second, it is liable to contain much sulphur and bone. The latter condi-

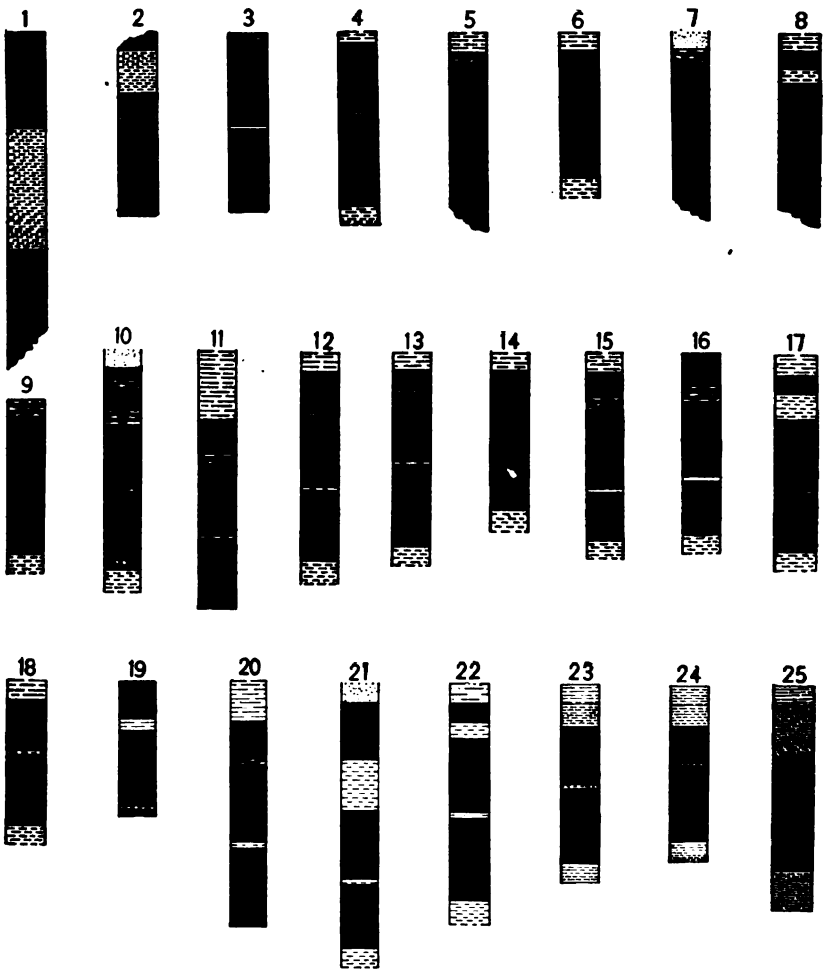

FIG. 7.—Sections of Coalton coal (Kentucky No. 7) in Chesapeake and Ohio Railway district. 1, Hills southwest of Ashland; 2, near Summit; 3, Princess Land and Mining Company, Princess; 4, Richard Jauchius, east flank of ridge between Mavity and Coalton; 5, east of Coalton; 6, Mavity; 7, 8, W. V. Sexton, head of Pigeonroost Creek; 9, James Sexton, Pigeonroost Creek; 10, Ashland Iron and Mining Company, head of Rush Creek; 11, 12, George Hull, Rush Creek; 13, John Runyon, North Fork Trace Creek; 14, Equilly Conley, west of Bellefont; 15, Straight Creek Mining Company, Straight Creek; 16, W. P. Clay, Straight Creek; 17, Morning Glory Coal Company, Grant; 18, Alex McAlvin, Cobb Fork; 19, Norton Branch Coal Company, Sandy Shoal mine (Ashley); 20, Adkins Coal Company, Rush; 21, Ashland Iron and Mining Company, No. 10; 22, Ashland Iron and Mining Company, No. 1; 23, Mile Branch, northwest of Kilgore; 24, Ashland Iron and Mining Company, No. 2; 25, Mile Branch, 1 mile northwest of Kilgore. Scale, 1 inch = 5 feet.

tion seems to prevail at the openings about Straight Creek and Denton. Though it varies greatly from point to point, it seems to be of

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workable thickness in some localities, as at the George Hull mines on Rush Creek (sections 11 and 12, fig. 7). A fair thickness of the upper bench was measured in the mine of the Straight Creek Coal Company and at the opening worked by W. P. Clay about a mile farther north near the Straight Creek Coal Company's tunnel, but in this locality the upper bench is too heavily impregnated with sulphur to be marketable (sections 12, 15, and 16, fig. 7). At the Morning Glory Company's mine near Grant it is of workable thickness but so variable that little dependence can be placed on it. In this mine 26 inches of coal were measured at one point and at others it is not present. A similar condition was observed by G. H. Ashley on Mile Branch. At most of the other openings visited the upper bench is too thin to be worked. The two lower benches are almost always workable, but even this statement needs some qualification. For example, a measurement on this bed in the hills southwest of Summit gave a thickness of 6 inches to the upper of these two benches and on Mile Branch two measurements by Mr. Ashley show 1 foot of coal at two different points. Exceptional thinning was also noted in the main lower bench, as indicated by the measurements obtained at the Sandy Shoal mine near Rush, where it is only 2 inches thick (section 19, fig. 7). These exceptional figures for the two lower benches of this bed do not destroy the value of the general statement that these benches are usually of workable thickness. They are mined together, the bony parting being separated by hand. They average very close to 20 inches each, the lower being usually slightly thicker than the other. The two benches range collectively from about 3 feet 3 inches to 4 feet, a fair figure for the bed as a whole being about 3 feet 6 inches, not counting the bony parting. As much as 4 feet 9 inches of coal has been seen, though this figure must be regarded as altogether exceptional. No average minimum thickness can be given, for the coal varies from the figures given above to a mere knife-edge and in places completely pinches out. In the description of the general geology of this district a mass of sandstone was described as usually overlying the coal. As a rule it does not immediately overlie the coal, but where it does the coal suffers and at some places may be reduced to only a few inches in thickness. The operations on this bed near Coalton have long since been suspended and a measurement in the hills to the east was obtained at a small roadside bank (fig. 7, section 5). This measurement indicates a possible coalescence in the two lower or main benches. A similar condition of affairs was observed at the country banks of James and W. V. Sexton at the head of Pigeonroost Creek (fig. 7, sections 7 and 9).

The roof of a coal, though not a part of the bed itself in the strict sense of the word, is nevertheless of great importance, for on its

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character may depend the margin of profit that justifies the mining of the coal. The roof of the Coalton bed is usually shale and is considered to be fairly strong. It ranges in thickness from a few inches to as many feet. In some places this shale is sandy; in others it is replaced by a massive sandstone, the coal in many such places being very thin. At the George Hull's opening near the head of Rush Creek a few feet of cannel shale were seen above the coal. The cannel shale was also observed at an opening owned by John Runyon on North Fork of Trace Creek. This shale sometimes scales off or "draws" and gives more or less trouble in the entries, but in the rooms little or no difficulty was reported from this source. The floor of the coal is apt to roll somewhat, but this is not common. Faulting is rare and where present is very slight. Small faults with a throw of 18 inches were reported near Rush at the Ashland Iron and Mining Company's opening No. 10. The superintendent of the mine reported that the largest fault known to him in the region around Rush was one near Star Furnace, with a throw of 6 feet.

Chemical aspects.—The coal itself is bituminous, but the two workable benches are not exactly alike. The upper bench is soft and lustrous and breaks into thin blocks or slabs along charcoal layers, a characteristic very common among the coals of this region. The lower bench is much harder as a rule than the upper bench and contains dull bands of splint coal. This coal is not gaseous. It is a dry-burning, noncoking coal now widely used in this part of the State for steaming and domestic purposes, and in the last three decades it has acquired an enviable reputation as an iron-making coal, being still used in the raw state for this purpose by the Ashland Iron and Mining Company at its furnace in Ashland. Its application to iron making began in 1866, when it became evident that the timber supplies which had furnished charcoal for the numerous furnaces situated in the Hanging Rock region were on the wane. Its use has continued down to the present time, naturally decreasing as many of the furnaces shut down on account of the high cost of mining the iron ore of this region as compared with the cost of Lake Superior and Alabama iron ores.

The analyses of this coal show a rather high percentage of sulphur for an iron-making coal. The coal mined along Williams Creek near Rush by the Ashland Iron and Mining Company was formerly washed and coked before using, but since the company's washer in Ashland was destroyed the coal is used raw. The ash is somewhat variable, but in the amounts of volatile combustible matter and fixed carbon the coal shows a very uniform character, as will be seen from the following seventeen analyses:

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Analyses of Coalton coal from northeastern Kentucky.

	1.	2.	3.	4.	5.	6.	7.	8.
Water	4.80	5.00	4.06	4.40	3.30	7.70	6.40	6.60
Volatile combustible matter	34.20	34.50	34.24	31.10	33.30	28.16	27.22	34.36
Fixed carbon	54.90	55.40	54.70	57.90	57.60	53.04	58.88	54.64
Ash	6.10	5.10	7.00	6.60	5.80	11.10	7.50	4.40
Sulphur	1.31	1.29	1.85	2.10	2.48	1.06	.97	.72
Coke	61.00	60.50	61.70	64.50	63.40	64.14	66.38	59.04

	9.	10.	11.	12.	13.	14.	15.	16.	17.
Water	6.06	6.40	4.40	3.20					5.19
Volatile combustible matter	32.94	31.40	38.00	35.06	35.20	39.90	38.40	42.51	32.87
Fixed carbon	54.80	57.66	52.86	54.40	43.30	53.30	54.75	52.06	55.57
Ash	6.20	4.54	9.14	7.34	21.50	6.80	6.85	5.43	6.57
Sulphur	1.87	1.67	2.20	2.63	1.30	2.05	2.05	1.32	1.68
Coke	61.00	62.20	62.00	61.74					62.30

1. Average sample of coal from stock house at Ashland furnace, representing coal as actually used in the furnace. Sampled by P. N. Moore.

2–5. From rooms in mine No. 4 of Ashland Coal Company near Coalton, Boyd County. Sampled by P. N. Moore.

6–8. From the upper, middle, and lower benches of the coal bed at the old Star Furnace mines above the furnace near the mouth of Rachel Branch, west of Kilgore. The samples were taken from the pillars which had been exposed for some time and probably contained less sulphur than the freshly broken coal. Sampled by A. R. Crandall.

9 and 10. From the upper and lower benches of the coal, here consisting of but two members, at an opening on Gum Branch of Straight Creek, Mount Savage Furnace property, Carter County. These samples were selected from coal on the dump and hence are probably not so nearly representative as those taken in the mines. Sampled by P. N. Moore.

11. From the old Watson drift on Lost Creek, near Willard, Carter County. Sampled by P. N. Moore.

12. From several rooms in the mine west of Dry Fork at Willard, Carter County, main entry. Sampled by P. N. Moore.

13–16. Analyses furnished by the superintendent of the furnaces of the Ashland Iron and Mining Company at Ashland; owing to their incomplete character they are not so good as the other analyses.

17. Average of first twelve analyses.

As will be seen, most of the analyses are of coals collected by P. N. Moore and A. R. Crandall and published in the report of the Kentucky Geological Survey on the eastern coal field (vol. C, p. 181). These samples were collected by "cutting a large number of pieces of coal from the whole thickness of the bed, taking them in regular succession from top to bottom, thus representing the coal exactly as it appears at the place of sampling. Slight partings of pyritous bands, large enough to be rejected in mining, were not of course represented in the sample, but otherwise impurities were taken if they occurred at the place of cutting. Wherever possible the sample was taken from a number of rooms in each mine, or, where the coal was not opened, from as many outcrops as possible. The constant endeavor has been to secure samples representing the coal as it actually occurs in the mines." The analyses of these samples were made by Robert Peter and Mr. Talbutt, of the Kentucky Geological Survey.

Some striking facts are brought out by the foregoing figures. The main feature is the remarkable uniformity displayed over the broad area from which the samples were collected, indicating care on the part of the samplers and uniformity in the methods employed.

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The average of Peter's and Talbutt's analyses is given in column 17 and shows how slightly most of the analyses deviate from the average. The figure for ash, given in analysis 6, is of interest and corroborates a statement made earlier in this bulletin as to the bony character of the topmost of the three benches. It is this bony character in conjunction with its high sulphur content that stands in the way of its exploitation even where it is of workable thickness. The content of sulphur at first sight seems rather high for an iron-making coal. If all this sulphur went into the iron it would perhaps spoil the product, but figures indicating the amount of sulphur in all the raw materials used in the charges as well as in the pig iron are necessary to indicate the way in which this constituent is distributed in the slag and pig.

The coal is not an iron-making coal through its entire extent, but only at certain localities, and even in a given mine the variation in the impurities may be such that only certain rooms or entries can be worked for furnace coal.

This bed has been regarded as the equivalent of the Hocking Valley coal of Ohio, of which Orton says[a] that "as a furnace coal it is not surpassed in the State and scarcely by any known bituminous coal." A comparison, therefore, between the Coalton coal of Kentucky and the Hocking Valley coal of Ohio and other coals which in the past have been used in the raw state in the blast furnace may have some interest. The following analyses represent coals which according to Moore have been applied for such use in Ohio, Indiana, and Illinois:

Analyses of iron-making coals from the east-central coal field.

	1.	2.	3.	4.	5.	6.	7.	8.	9.
Water	5.19	5.93	5.64	6.22	8.57	4.96	6.21	13.82	6.49
Volatile combustible matter	32.87	36.48	36.51	32.55	32.70	34.62	34.29	35.16	41.88
Fixed carbon	55.57	52.41	52.21	56.57	55.43	56.03	54.78	49.96	46.45
Ash	6.57	5.13	5.73	4.66	3.30	4.39	4.72	1.06	5.18
Sulphur	1.68	1.09	1.57	.95	.47	.62	.62	1.47	2.93

1. Average of twelve analyses of Coalton coal in northeastern Kentucky.
2. Average of ten mines of the Hocking Valley. Ohio Geol. Survey, vol. 5, 1884, p. 924. N. W. Lord, analyst.
3. Average of upper, lower, and middle benches of the Nelsonville, Ohio, bed. Ohio Geol. Survey, vol. 5, 1884, p. 975. N. W. Lord, analyst.
4. Average of eighteen samples from the great bed in the immediate valley of the Hocking and about Straitsville. Ohio Geol. Survey, vol. 3, p. 683.
5. Jackson Shaft coal, Jackson County, Ohio. Ohio Geol. Survey, vol. 5, 1884, p. 1015. N. W. Lord, analyst.
6 and 7. Lump coal from bed No. 1, Schmidgall Coal Company, Murphysboro, Jackson County, Ill. Composition and character of Illinois coals; Illinois Geol. Survey, Bull. No. 3, p. 70. S. W. Parr, analyst.
8. Brazil block coal from No. 1 shaft, Brazil Block Coal Company, Clay County, Ind. Twenty-first Ann. Rept. Indiana Dept. Geol. Nat. Res., 1896, p. 106. W. A. Noyes, analyst.
9. Brazil block coal from No. 3 shaft, Brazil Block Coal Company, Parke County, Ind. Twenty-first Ann. Rept. Indiana Dept. Geol. Nat. Res., 1896, p. 186. W. A. Noyes, analyst.

[a] Ohio Geol. Survey, vol. 5, 1884, p. 923.

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These analyses of Ohio, Indiana, and Illinois coals show a fairly close agreement with the average analysis of the twelve samples of the Coalton coal of northeastern Kentucky. The figures for volatile combustible matter and fixed carbon are exceptionally close; the ash, moisture, and sulphur show considerable variation. The above analyses, taken from the various State reports, may be compared with analyses of samples collected by P. N. Moore and A. R. Crandall from the same beds in the different States mentioned. The mode of sampling was the same as that followed in the Kentucky field, and on account of this uniformity in sampling the results of the analyses given on page 71 and those which follow are really more strictly comparable:

Analyses of iron-making coals from the east-central coal field.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
Water	5.19	3.26	3.74	4.40	4.54	2.62	3.44	2.40	2.70	2.68	3.46
Volatile combustible matter	32.87	33.76	36.32	35.08	29.68	32.01	31.86	35.10	36.38	36.32	32.64
Fixed carbon	55.57	54.42	55.74	55.20	57.06	58.78	59.54	55.50	55.64	53.58	53.80
Ash	6.57	8.56	4.20	5.32	8.72	6.76	5.16	9.00	5.28	7.42	6.10
Sulphur	1.68	2.247	1.299	1.659	0.758	2.472	1.370	2.373	1.664	1.803	1.848
Coke	62.30	62.98	59.94	60.52	65.78	65.34	64.70	62.50	60.92	61.00	59.90

1. Average of twelve analyses of samples of the Coalton or No. 7 coal from northeastern Kentucky.
2, 3, and 4. Hocking Valley or Nelsonville coal, from mine near Nelsonville, Ohio. 2 is from the upper, 3 from the middle, and 4 from the lower division of coal.
5. From the well-known Jackson shaft coal of Ohio.
6 and 7. From two of the best mines in the Big Muddy coal region, near Murphysboro, Ill. Large quantities of coal from both of these mines have been used in the furnaces at South St. Louis.
8, 9, and 10. Indiana block coal, from vicinity of Brazil, Ind. Samples representing the coals from three different mines. Each sample was taken from several rooms in the same mine, so as to represent the mine as fairly as possible. These mines rank among the best of that region, and coal from all of them has been successfully used in the furnace for making iron.
11. From the Sheridan mines, Lawrence County, Ohio.
2–5 and 11 sampled by A. R. Crandall; 6–10 sampled by P. N. Moore.

The results show a surprising uniformity, and though the Kentucky coal shows a higher moisture content than the other coals, yet in other respects, especially when the amount of sulphur is considered, it compares favorably with the iron-making coals of Ohio, Indiana, and Illinois.

Amount of coal.—The question of the amount of high-grade coal which is still available is of great importance. The extent of the territory above drainage level underlain by the Coalton coal can be readily seen on the economic map (Pl. I). It should be borne in mind, however, that in the region where this coal is indicated as lying above drainage level it has been largely worked out and, as has been mentioned, most of the mines now working it are nearly in a state of exhaustion. The eastern limit of the coal above drainage level is indicated on the economic map. This coal has never been exploited beyond this line by shafts. It has been mentioned (p. 46) that in the

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valley of Big Sandy River its character is such that it may never become commercially available, but all over the district now under consideration it has been justly relied on as a uniform and persistent bed. Just where the coal begins to change its character from a workable to a nonworkable bed is, of course, problematical. But it is reasonable to suppose that the change to the condition observed along Big Sandy River on the south side of the basin may be gradual and that there may prove to be a very considerable body of workable coal below drainage level on the western side of the basin. Thus far prospecting with the diamond drill has not been attempted and the eastern limits of workable coal are still in doubt. The coal will have to be worked by shafting and must be approached with the plan of working up the rise—that is, to the north or to the northwest. On account of the uncertainty connected with the exact zone of change from a commercial to a noncommercial bed, it has seemed inadvisable to make an estimate of the good coal still available. It is believed, however, that the amount is large and will repay careful prospecting with the diamond drill.

WINSLOW COAL (NO. 6).

Geologic position.—The next lower workable coal in this district is known as coal No. 6 in the Kentucky reports. It is known as the "limestone coal" in the region about Ashland, Ky., from its position as the first really important bed above the Vanport ("Hanging Rock") limestone. The names Keyes Creek and River Hill coal are also applied to it. In Ohio this bed is known as the Newcastle coal[a] and is correlated with the Lower Kittanning of Pennsylvania. It is usually found about 20 feet or more above the Vanport limestone or ore, and its distance below the Coalton is from 40 to 50 feet. About midway between the two coal beds is the red kidney iron ore. These three well-known horizons should serve to readily identify this bed of coal. Near Ashland, Ky., and Coalgrove, Ohio, the rocks associated with it are massive sandstones and all over the northeastern part of the district where this coal is workable the beds both below and above it are prevailingly sandy. The conditions under which the top of the Pottsville formation was deposited seem to have continued into early Allegheny time.

Extent.—The outcrop of the coal where workable has not been indicated on the map, for the Winslow lies so close below the Coalton coal that the representations of the two would be well-nigh indistinguishable. The Winslow outcrops in the northern part of Boyd County, where it is extensively mined and used. Outside of this part of the quadrangle the coal, so far as known, is not workable

[a] Ohio Geol. Survey, vol. 5, 1884, p. 122.

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over any great area. It is particularly important about the city of Ashland. Along Little Hood Creek it is present in the hills on both sides, and near Pollard, Oakview, Winslow, and Summit there are openings on nearly every farm. On account of its development about Ashland it was thought that the name "Ashland coal" might be applicable, but the next higher workable coal, or Coalton bed, is sometimes inappropriately known by that name. The name "Winslow coal" will be used in this report, as the bed is now being mined on a commercial scale at Winslow on the Chesapeake and Ohio Railway, a short distance southwest of Ashland. This bed of coal is present in all the hills between Little Hood and Catletts creeks, along Ohio River, and on Keyes Creek.

Development.—It is extensively developed in a small way in the northern part of Boyd County. In most places, however, the operations are on a small scale, most of the railroad mines apparently being closed, with the exception of mine No. 8 of the Ashland Iron and Mining Company at Winslow. About Ashland the coal is extensively mined at small banks and hauled in wagons to the city, where it supplies the local demand for fuel, and is used also by the Ashland brick plants, by the river boats, by the furnaces of the Ashland Iron and Mining Company for generating steam, and in other ways up and down Ohio River. It is highly regarded as a steaming coal and retails in Ashland and Catlettsburg at 8 or 9 cents a bushel.

Character.—The Ohio reports state[a] that coal from this bed has furnished the entire supply of Ironton for manufacturing and domestic purposes and that upon the mines of this bed all the manufacturing interests of Ironton have been built. This is very high praise for a bed of coal. The section of this bed, together with the quality of the coal around Ironton, are strictly comparable with similar features of the coal at Ashland. The two towns lie within sight of one another. The accompanying sections (fig. 8) give a fair idea of the thickness of the coal.

From the sections it will be observed that the coal usually occurs in three benches, the upper two separated generally by a thin bone parting, rarely more than 1½ inches thick. These top benches without the bone parting range in the aggregate from 2½ to 3 feet in thickness. They are separated from the lower bench by a clay or shale layer 3 to 8 inches thick. The lower bench is from 6 inches to 2 feet thick and is usually worked. The roof of the coal is sandstone, though in places between the top of the coal and the base of the overlying sandstone a few inches of dark shale is present. The sandstone locally thickens up and replaces the coal completely, and rolls of a few square feet in area are not uncommon. Some slight faults are reported. The floor of the coal is usually clay. The coal

[a] Ohio Geol. Survey, vol. 5, 1884, p. 1044.

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in the upper two benches is splinty and harder than that in the lower bench, which crushes badly in the pillars. Like the other coals in the district, the upper two benches readily break into blocks or slabs 6 inches or more thick. The coal should be classed, therefore, as a semiblock coal. It is not a good coking coal, but after being washed has been made into coke by the Ashland Iron and Mining Company and used in the furnaces in Ashland. The coke is apt to be soft and spongy and contains a rather high percentage of sulphur. The results obtained, however, when mixed with a small amount of Pocahontas coke were satisfactory, and a very good coke was made by mixing it with a small amount of Kanawha coal and coking the mixture. Like all the coals in this district, it bears stocking and transportation well.

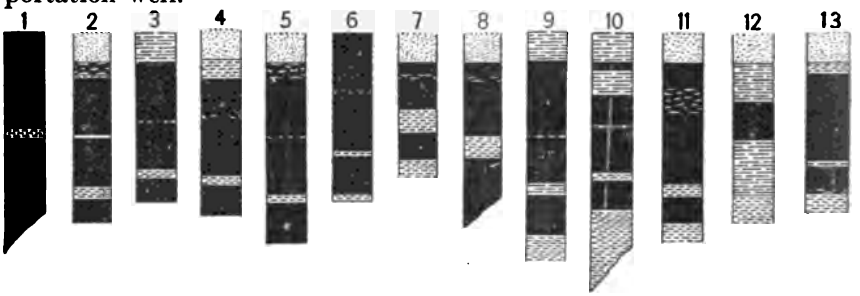

FIG. 8.—Sections of Winslow coal (Kentucky No. 6) in northern part of Boyd County. 1, 2, County road one-half mile east of Winslow; 3, Ashland Iron and Mining Company, William Wurtz, lessee, near Winslow; 4, Mrs. George McKnight, three-fourths mile north of Winslow; 5, Nancy McKnight, three-fourths mile northeast of Winslow; 6, Ashland Iron and Mining Company, No. 8, Winslow; 7, J. M. Ferguson, south of Ashland; 8, James Patten, Keyes Creek; 9, near Oakview (Ashley); 10, John Gerard, near Oakview (Ashley); 11, in hills west of Ashland; 12, Rush; 13, Newcastle coal, Ohio, section at Newcastle. Ohio Geol. Survey, vol. 5, 1884, p. 1044. Scale, 1 inch = 5 feet.

Analyses of Winslow coal.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Moisture			5.19	3.40	2.94	2.70	4.04	3.65		
Volatile matter	43.52	42.95	41.86	32.30	32.50	36.70	33.60	36.59	40.17	2.97
Fixed carbon	50.54	52.10	47.69	55.40	56.70	52.60	53.34	52.62	51.49	88.26
Ash	5.94	4.95	5.26	8.90	7.74	8.00	9.00	7.11	8.34	8.77
Sulphur	1.83	2.54	1.40	1.23	1.97	1.71	1.31	1.71	1.57	1.24

1. Mine No. 12 of the Ashland Iron and Mining Company near Winslow, Ky.
2. West of Ashland.
3. Newcastle coal from tunnel mines near Ironton, Ohio. Ohio Geol. Survey, vol. 5, 1884, p. 1045. N. W. Lord, analyst.
4. Turkey Pen Hollow.
5. Keyes Creek.
6. Horse Branch.
7. Amanda furnace.
8. Average of first seven analyses.
9. Washed coal from Ashland Iron and Mining Company's No. 8 mine at Winslow.
10. Coke from No. 12.

Analyses 1, 2, 9, and 10 furnished by the Ashland Iron and Mining Company; 4, 5, 6, and 7 by Peter and Talbutt, Report on the eastern coal field: Kentucky Geol. Survey, vol. C, p. 21.

The analyses of this coal show discrepancies so great that it is difficult to say which represents the average for the region. The

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analyses furnished by the Ashland Iron and Mining Company are unfortunately incomplete, but if the moisture in them is considered a part of the volatile matter some idea of the latter constituent may be had by subtracting the average moisture in these analyses where it is given from the volatile matter, in which it is apparently included. The results obtained by this process indicate a content of volatile matter between that given by Peter and Talbutt's figures and that given by Lord. Averaging these results with those given in the last five analyses, the volatile matter represented in all will average about 36.59 per cent. Other averages are given in column 8. The results are fairly characteristic of a bituminous coal of high grade. The percentages of fixed carbon and volatile matter indicate a good gas coal, but of course a coal furnishing only a second-grade coke would hardly be used for gas making. Though the coal has been washed and coked, it furnishes a nonmarketable product. Coke from this coal has never been used alone in the furnace, but always with some standard coke, like Pocahontas and Kanawha coke.

As a steam fuel the coal gives excellent satisfaction. Its average analysis, indicated in column 8, shows a very close resemblance in composition to the average analysis of the Coalton coal in this region, which is highly regarded as a steam coal. It contains less moisture than the Coalton coal, but more ash. The sulphur in the average analyses of these two coals is about the same and the volatile matter and fixed carbon in both coals are very close. In the Coalton coal the fuel ratio—that is, the quotient of the fixed carbon divided by the volatile matter—is 1.69 and in the Winslow coal this ratio is 1.43, a difference of about 0.25.

The sulphur content of the Winslow coal is rather high, but with respect to its content of moisture and the percentages of fixed carbon it compares very favorably with the good grades of bituminous coal of Ohio and Illinois. It does not rank with the best West Virginia, Pennsylvania, Kentucky, Virginia, and Arkansas coals.

Amount of coal.—This coal has been described as one of the more important beds in the southern part of Lawrence County, Ohio. It is equally important across Ohio River on the Kentucky side about Ashland. Its area of greatest development also is confined to this region. Southward about Cannonsburg and Princess this bed gradually becomes thinner, until at Rush, where the following section was obtained, the coal becomes too thin to have any commercial value whatever:

Section of Winslow coal at Rush.

	Feet.
Shale, blue, some of it light in color	1
Coal	1
Shale, black	1½
Fire clay.	

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It thus appears that in the region where the Winslow coal is best developed the next overlying coal is not developed on a workable scale, and vice versa.

Coal No. 5 is reported by Crandall as having been worked near Buena Vista furnace, on Straight Creek, Boyd County, and though badly broken up by partings shows 38 to 40 inches of good coal.[a] Crandall's section at this point is as follows:

Section of No. 5 coal bed on Straight Creek.

Shale.	
Coal and shale.	Inches.
Shale	6
Coal	5
Shale	5
Coal	27
Shale.	

Peter and Talbutt[b] found the composition of this coal to be—

Analysis of coal No. 5 near Buena Vista furnace, on Straight Creek.

Moisture	3.20
Volatile matter	32.30
Fixed carbon	53.00
Ash	11.50
Sulphur	2.00

No openings on this coal were noted by the writer.

POTTSVILLE COALS.

A brief description of the rocks of the Pottsville formation has been given on pages 19–20, 62–64. It has been stated that the rocks of this formation are prevailingly sandy, and that associated with these sandy beds, which may be pure sandstone, sandy shale, or shaly sandstone, are three classes of economic deposits—coal, fire clay, and iron ore. In this place only the coals will be considered.

CATLETTS CREEK COAL (NO. 4).

Geologic position.—The highest coal in the Pottsville formation in this district may be called the Catletts Creek coal from the fact that it is exploited along the creek of that name. It corresponds stratigraphically with the Upper Stinson coal at Boghead and with the Lick Creek coal of the Big Sandy Valley district. Its position directly below the Homewood sandstone serves to locate it at once in the geologic column. Its distance above the next lower workable coal in this district is probably not more than 40 to 50 feet, and it lies approximately the same distance below the Vanport ("Hanging Rock") limestone in the Allegheny formation in the eastern part of Ashland, though this measurement depends largely on the varying thickness of the Homewood sandstone.

[a] Kentucky Geol. Survey, vol. C, 1884, p. 19. [b] Idem, p. 20.

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Extent and development.—Although this coal outcrops over a broad area in the district, it has proved of workable thickness in very few places. Its outcrop, if drawn on the map, would come a little below that of the clay indicated by the red line.

In the eastern part of Ashland it has been prospected at numerous points on the road leading to the city cemetery. Farther up Ohio River, at the Weaver Pottery Company's plant, between Sandy City and Catlettsburg, it was formerly worked, but the bank had fallen shut at the time of the writer's visit. It is probable that this coal may be of workable thickness between this point and Ashland, although there is a possibility that it may be replaced by the massive Homewood sandstone of this region. On Catletts Creek it is workable and may be easily traced for 2 miles west of Catlettsburg to a point where it disappears below drainage level. In the valley of Hood Creek, a short distance northwest of Summit, it has been opened by William Crane, and near the mouth of Shope Creek A. J. Harris, on whose land the coal has been opened, reports 3½ feet of coal with an important fire clay below. At Music it has been opened, but is so badly broken by partings as not to be a commercial coal. So far as known, it is not workable at any other point in the district. Developments on this coal are not on a commercial scale. In all the localities described above, except at the opening of the O'Kelly Brick Company, it is worked only during the winter months for local trade.

Character.—The reason for its restricted exploitation is at once evident from its section. It is, in fact, a thin coal bed, and this character, in connection with the fire-clay parting running through the center of the bed, will probably bar it from the list of commercial coals of this district for some time to come. Both benches nowhere measure more than 2½ feet together, and the parting in the middle is in places as thick as one of the benches of the coal. It usually has an excellent roof of massive sandstone, which makes it a safe and cheap coal to work. Its clay floor is important commercially, for it it is of workable thickness and of a quality good enough to serve as a bond in refractory brick. The coal could readily be worked at a profit in connection with the fire clay, and this seems to have been understood by one firm, the O'Kelly Fire Brick Company, which mines the clay and coal in the eastern part of Ashland (fig. 9, section 3). The coal is of the lustrous bituminous variety, but contains splinty bands and is on this account rather hard. It breaks into thin slabs and hence is blocky in its nature.

TORCHLIGHT COAL (NO. 3).

Geologic position.—The next lower workable coal in this district is at a distance of 40 or 50 feet below the base of the Homewood sandstone and hence at the same distance below the Catletts Creek coal.

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East of Danleyton it has been opened, together with the coals occurring below it, at a few points about 80 feet below the top of the Homewood sandstone, which, in this region, is a prominent cliff maker and can be readily traced. This is not the second coal below the base of the Homewood sandstone, as on the Hood Creek pike two small beds were observed at small distances above this coal. It is very probable, however, that it is the next main workable coal below that occurring immediately beneath the Homewood sandstone. It is also certain that this coal, which is the one opened on the lands of the Means Russell Iron Company in the valley of Hood Creek, can not be the Catletts Creek coal, for the two coal beds are found in the section exposed from the point where the main Hood Creek pike crosses Hood Creek northwest of Pollard to the Flatwoods area. It is probable that it is the equivalent of the Torchlight coal of the Big Sandy River

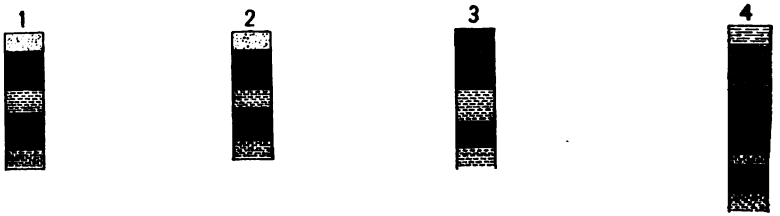

FIG. 9.—Sections of Catletts Creek (Kentucky No. 4) and Torchlight (Kentucky No. 3) coals in Boyd County. Catletts Creek coal: 1, Alex. Chapin, Catletts Creek; 2, country bank, Catletts Creek; 3, O'Kelly Brick Company, Ashland. Torchlight coal: 4, Hood Creek, west of Ashland. Scale, 1 inch = 5 feet.

region, and of the Lower Stinson coal at Boghead, and hence is No. 3 in the Kentucky series.

Extent and development.—This coal bed is present above drainage level in workable thickness over only a small part of Boyd County. Both to the east and to the south the dips carry it below drainage level. To the west and south, however, in Greenup and Carter counties, it is found above drainage level, having a wide distribution near the western limits of the quadrangle. Within this district it has been worked on only a small scale, owing to the fact that it is thin and badly broken by partings, but along Canes Creek and Stinson Creek in Greenup and Carter counties it is one of the most important cannel coals. It is present in workable thickness in the ridge separating Little Sandy River from East Fork, but on the eastern flank of the ridges it is not worked, except at a few country banks. Its outcrop, where known to be workable, is indicated on the economic map (Pl. I). The most important past development on this bed was in the valley of Hood Creek, west of the city of Ashland, directly overlying a massive sandstone. Though it has been opened in many places northwest of Pollard on the lands of the Means Russell Iron Company, all the openings have for some reason

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been allowed to fall in. The section and character of the coal here are unknown. The following is a section of the bed:

Section of No. 3 coal bed of the Kentucky Geological Survey in the valley of Hood Creek, west of Ashland, Ky.

	Inches.
Shale roof.	
Coal with bony streaks	15½
Coal, bituminous, with splint bands	18
Clay	3½
Coal	9
Fire clay.	

The bank is situated so that it is often flooded at periods of high water. The above section is the only one in this district which the writer had an opportunity to measure; hence it would be unjust to base a judgment as to the character of the coal on such slight evidence. It is apparent at once that if the section is a true criterion of the bed, it has little market value at present. The upper bench, which is the main workable bench, may be all coal in many places and not largely bone as indicated. If this bony character is not widely prevalent the upper bench alone would have commercial possibilities. The parting between the two benches, in connection with the thinness of the lower bench, injures the value of this bed.

The coal in the upper bench is hard and contains splint bands, and like most of the coals in the region will bear stocking and transportation without much crumbling. On this account it is a coal which can be shipped for long distances and not suffer much in transit.

DANLEYTON COAL.

Geologic position.—The position of the Danleyton coal bed in the geologic column is very plainly indicated in the section between Argillite and Hood Creek (p. 64). It is known locally as the "clod seam," owing to a clay parting which it contains. Openings on it have been made at many places near Argillite and Danleyton, and it may be called the Danleyton coal. It occurs 110 feet below the base of the Homewood sandstone and from 30 to 40 feet below the horizon of an ore bed which must have been of considerable importance in the region, as it has been benched to a great extent. This ore has been regarded by Moore as the main block ore,[a] but its relations to the base of the Homewood indicate a lower ore. Certainly the coal opened below it is much too far below the Homewood to be regarded as the equivalent of the No. 3 or Torchlight coal.

Extent.—The Danleyton coal is present in the hills bordering East Fork of Little Sandy between Danleyton and Naples, but south of Naples it is below drainage level. Near Argillite it occurs 150

[a] Kentucky Geol. Survey, vol. C, 1884, p. 138.

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feet above railroad grade, and has been opened in the surrounding hills. There is an almost continuous line of country banks on the outcrop where it is above drainage level on Culp and Henry branches, and nearly every farmer about Danleyton also has opened this coal for his private use. A short distance east of Danleyton it goes below drainage level. It has been opened near Hunnewell, on the Eastern Kentucky Railway, as described elsewhere (p. 92). At all these points the development is purely local.

Character.—The accompanying sections (fig. 10) illustrate the character of this coal. They show a striking similarity in their general features. The coal where seen is always in two benches, separated by a clay parting. Each bench ranges from less than a foot to 1½ feet in thickness. The lower 4 or 5 inches of the upper bench is in places bony. The clay parting ranges from 6 inches to more than a foot in thickness. In no place was more than 31 inches of good coal seen in both benches. The coal is of the usual bituminous variety. The upper bench is perhaps more lustrous than the lower, but

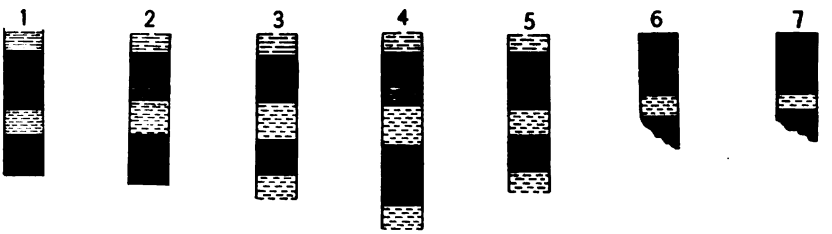

FIG. 10.—Sections of Danleyton coal. 1, Mouth of Pigott Branch; 2, J. H. Pruitt, Culp Creek; 3, mouth of Pigott Branch; 4, Henry Branch; 5, A. W. Callahan, Danleyton Church; 6, south of Danleyton; 7, Turkey Fork. Scale, 1 inch = 5 feet.

it may also be dull and splinty. The lower bench locally breaks out into blocks and contains splinty bands. The thinness of this bed and the presence of the clay parting are serious hindrances to its commercial possibilities. So long as thicker coals are prevalent in the region this bed can hardly compete with them in the trade. It is conveniently situated with respect to transportation, and in the future may be developed for shipment. It is reported to be an excellent stove and steam coal, and is widely used by the farmers.

LITTLE SANDY VALLEY OR EASTERN KENTUCKY RAILWAY DISTRICT.

EXTENT.

The Little Sandy Valley district is in the northwestern part of the Kenova quadrangle. Its eastern boundary is the ridge separating the drainage of East Fork of Little Sandy and Williams Creek from that flowing into Little Sandy River. It will be seen that this is an irregular line running southwest from the northern edge of the quadrangle to the ridge just west of Means tunnel. Southwest of

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this point the boundary swings west and south to Mount Savage, thus allowing a part of the Little Sandy drainage basin to be included in the Chesapeake and Ohio Railway district. The line of the Chesapeake and Ohio Railway has been arbitrarily chosen as the southern limit of this area. The reason for the choice of these boundaries is that the district thus set apart is a unit commercially, all the coal mined in it being shipped over the Eastern Kentucky Railway, which follows Little Sandy River more or less closely till it reaches Ohio River.

GEOLOGY.

This district lies on the northwest side of the basin, which extends nearly across the quadrangle from its northeastern to its southwestern border. The beds dip southeast. It will be seen at once that from the center of the basin to the northwestern edge of this area lower and lower beds appear in the valleys. Therefore the lowest beds stratigraphically are those in the valley of Tygarts Creek.

The rocks outcropping in this district occur in both the Pennsylvanian and the Mississippian series. The former series in this district includes the Pottsville formation and a part of the Allegheny. The Mississippian series includes the Maxville limestone lying at its top and a part of the Waverly group.

The Allegheny formation is, for the most part, confined to the hills east of Little Sandy River, but its base is present in the tops of some of the highest hills between Little Sandy River and Tygarts Creek.

The next lower formation is the Pottsville. Considered from both an areal and an economic standpoint this is the most important formation of the region. Its entire thickness is represented and, since it differs so markedly from its equivalent in the Big Sandy River region, it has been thought advisable to prepare a general columnar section which will represent it in this district (Pl. IV, p. 28). It includes the rocks from the top of the Maxville limestone to the top of the Homewood sandstone, in all very nearly 400 feet. In some places it may be thicker than this, but in others its thickness may be nearer 300 feet. The prevailing character of the rocks in this formation is sandy. Lying 20 to 30 feet above the Maxville limestone occurs the lower and one of the most important sandstone members in the Pottsville—the "conglomerate rock" or "conglomerate formation" of the Kentucky Geological Survey. It is not a simple sandstone at all points; on Everman Creek a distinct black shale which locally contains coal occurs near its middle. The fossils obtained from this shale point to its equivalence with the Jackson shaft coal of Ohio and the Sharon coal of Pennsylvania. At the top of the Pottsville is another important sandstone member, the Homewood sandstone, ranging from 25 to 50 feet in thickness in this particular district, though in other parts of the area it may attain a thickness

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of 100 feet or dwindle to a few feet of sandy shale. There are other important sandstones in this area; for example, below the Danleyton coal about Argillite and Hunnewell a massive sandstone 60 to 70 feet thick shows in the hills, and locally the shaly sandstones and sandy shales so characteristic of this formation assume a decidedly sandy phase, becoming, in fact, true sandstones. The deposits of chief economic interest in the Pottsville are coal, clay, and iron ore. There are at least four different coal horizons, attaining importance in different parts of the district, and if the thin beds which are used locally but which may never assume much commercial importance be counted the number is considerably increased.

The next lower member in the section is the Maxville limestone. This rock has some economic importance but does not contain any coal beds. It is very restricted in its distribution; it outcrops on Everman Creek at a few points and in the valley of Tygarts Creek. It is not over 20 or 25 feet thick.

The Waverly group underlies the Maxville limestone. Its best development in this area is in the valley of Tygarts Creek. In the hills about Warnock G. H. Ashley measured a little over 100 feet of this group, composed of shale, shaly sandstone, and sandstone. The Waverly group has been divided into several formations, the topmost of which are the Logan, 100 to 150 feet thick, and the Blackhand, 50 to 500 feet thick. There are no grounds to warrant dividing the rocks below the Maxville into more than one formation in this area. They may be regarded, therefore, as belonging to the Waverly group. They are of minor economic importance, as they contain no coal beds, clay, or iron ore within the limits of this district.

THE COALS.

ALLEGHENY COALS.

The rocks included in the Allegheny formation in this district lie chiefly east of Little Sandy River and cover only a small part of the surface. The two important coal beds in the lower half of the Allegheny—namely, the Coalton and the Winslow—are present in small areas on the divide between Little Sandy River on the west and East Fork and Williams Creek on the east. These deposits in general are rather small to be exploited commercially, though in some localities considerable coal has existed. At the head of Stinson Creek, for instance, the Coalton coal is of some importance. The remaining coal beds of the Allegheny formation, outcropping along the eastern margin of the Little Sandy River region, owing to its southeastern dip, will be worked and shipped along the Chesapeake and Ohio Railway and are considered in the description of the district tributary to that line (pp. 60–82).

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POTTSVILLE COALS.

UPPER STINSON COAL (NO. 4).

Geologic position.—The highest workable coal in the Pottsville formation occurs near the base of the Homewood sandstone. It thus corresponds in position with the Lick Creek coal, south of Louisa, and the Catletts Creek coal. It is opened and worked at Boghead by the Kentucky Cannel Company, where it occurs 30 feet above the Lower Stinson coal. Strictly, then, this coal should be called coal No. 4, if we are to adhere strictly to a system of numerals for the coal beds. Both this coal and the underlying bed fall within the Mercer group of northwestern Pennsylvania.

Extent and development.—This coal has been called the "Yankee vein" near Hunnewell, and according to report has been worked near that place. It is of workable thickness over a fairly broad area. It is present and as a rule is of workable thickness in most of the hills of this district east of Little Sandy River. Workable thickness is

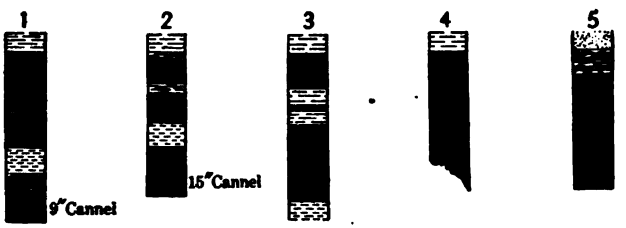

FIG. 11.—Sections of Upper Stinson coal (Kentucky No. 4). 1, 2, Kentucky Cannel Company, Boghead, Ky.; 3, Miss Drendy Jacobs, hill west of Canes Creek; 4, 5, Mount Savage. Scale, 1 inch=5 feet.

reported about Hunnewell, but its greatest thickness is to the southwest, in the hills at the head of Wilson and Upper Stinson creeks. In places it is a splint and bituminous coal, and at Boghead it contains an important cannel layer.

At the head of the smaller tributaries flowing into Wilson Creek from the east it is opened on the places of Miss Drendy Jacobs and C. G. Brammell. At an opening on Miss Jacobs's property the thickness of this bed is well shown (fig. 11, section 3). On the county road between Boghead and Seney its bloom shows, but the coal has not been opened and little is known of its thickness and character. On Lower Stinson Creek it is worked by the Kentucky Cannel Company at Boghead, and according to report the old Lexington and Carter Coal Mining Company worked the bed in the past in the hills southeast of the present openings of the Kentucky Cannel Company, shipping their coal overland to the Chesapeake and Ohio Railway at Music Still farther south, in the hills north of Mount Savage furnace, this coal has been opened and worked, though it is rather thin and badly

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broken by clay partings. At some of the prospects visited at other points near Mount Savage it shows an excellent section, as seen in fig. 11 (sections 4 and 5). This coal, therefore, is present in workable thickness over considerable territory lying between the heads of Canes Creek and Straight Creek. West of Little Sandy River it is present only near the tops of the highest hills.

Character.—It will be seen from a study of the sections of this coal bed that it is very irregular in thickness. The coal at Boghead is comparable with that measured west of Canes Creek at the bank of Miss Drendy Jacobs. At both these points the bed consists of three benches, separated by either bone or black clay or shale partings. The coal in the upper bench ranges from 7½ to 11½ inches, and in places has a few inches of bone over it. The middle bench ranges from 1½ to 11 inches and is of soft bituminous coal, as is the upper bench. These two benches are separated by a parting not exceeding 6 inches thick of bone or black shale. At Boghead the coal shows a bottom bench of cannel, varying between 9 and 15 inches, and separated from the middle bench by about 6 inches of bone or clay. In most places the coal bed has a clay floor and a shale roof which requires careful timbering. West of Cane Creek the coal in the upper two benches is soft lustrous bituminous coal, as at Boghead, but the bottom bench, which measures 2 feet or more, is splinty and dull. At Mount Savage the coal appears to be irregular, showing in one place the simple section indicated in sections 4 and 5 (fig. 11), but in other places being badly broken by clay or shale partings and having a roof of shale or clay or the massive Homewood sandstone. This coal is opened at many country banks near Mount Savage.

West of Canes Creek near the Greenup-Carter county line this coal is developed in three benches; the upper two are ordinary soft lustrous bituminous coal and the lower bench is hard and splinty. Both varieties are mined for local use in the region and give excellent results when used for domestic and steam purposes. At Boghead also the upper two benches are soft ordinary lustrous bituminous coal mined in connection with the cannel but kept separated from it. The cannel from the lower bench is peculiar in structure. It is not homogeneous and compact and does not break with the conchoidal fracture characteristic of the more familiar types of cannel coal when seen in large lumps. It is irregularly bedded, or lenticular, the individual beds or lenses varying greatly in their two larger dimensions. In places the width, however, is not more than an inch. The thickness of these lenses varies; in some places they are from a quarter to a half inch thick, but elsewhere they are exceedingly thin. Along the bedding planes are flecks of lustrous material. These may be due

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(1) to material of different composition originally or (2) to material which may possibly have undergone less physical change (maceration) before consolidation, or (3) some of these patches may be slickensided surfaces or planes of movement, suggesting the possibility that the structure of the rock may be secondary and due to movement after the coal had been deposited. When examined closely the material composing the lenses is seen to be typical cannel in every way, having the dull appearance of more massive cannel coal, breaking with conchoidal fracture, and being homogeneous and compact, all on a small scale. With the exception of the small lustrous patches and its structure when viewed in large-sized fragments, it is like more massive cannel coal. The coal mined from this bench is kept separate from the bituminous coal of the same bed and, with the cannel from the next lower bed, is shipped abroad, where it is used chiefly as a gas enricher, being very high in volatile matter and fairly low in fixed carbon and moisture.

LOWER STINSON COAL (KENTUCKY NO. 3).

Extent.—The next lower workable coal in the Pottsville formation occurs 30 feet below that just described. Thus, were the numbers applied to coals which are workable locally, this would really be No. 3 in the series. This is probably equivalent to the Hunnewell cannel coal. In the past it was extensively worked in the vicinity of Hunnewell furnace and the cannel in it was said to range in thickness from 3 to 4 feet. It is present in all the hills in this district east of Little Sandy River, becoming higher in the hills toward the west. North of Turkey Fork it seems to lose its cannel bench, but south of this stream it is worked by the Kentucky Cannel Company near Hunnewell for the cannel it contains. At the head of Canes Creek its bloom shows at several points along the road, but little prospecting has been done on it and not much is known of its character. Its most important area in this district, and, indeed, in the entire western part of the whole quadrangle, is the irregular square included between Lower Stinson Creek on the north, the limits of this district on the east, the Chesapeake and Ohio Railway on the south, and Little Sandy River on the west. In this area it is fairly uniform in thickness, though it varies somewhat in physical character. At Boghead it is worked by the Kentucky Cannel Company on a commercial scale, chiefly for its cannel bench, which occurs near the middle of the bed. On the waters of Upper Stinson Creek it has been opened at numerous points. West of this creek and between it and Little Sandy River the coal bed seems to lose its cannel bench at most points and to consist of two benches of ordinary bituminous and splint coal. In the hills about Robin Run and the small tributaries

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of Little Sandy River southeast of Grayson it has been opened at many points and in every place is of fair workable thickness. The persons on whose land the coal is worked and where measurements were obtained are named on page 89. Most of the hills west of Little Sandy River rise high enough to contain this coal bed, but at the time of the writer's visit apparently very little prospecting had been done on the bed in this region and its identity with the coal described southeast of Grayson could not be established with any great degree of certainty. What is considered the equivalent of the Lower Stinson coal has been opened on Barrett Creek and Everman Creek and contains some cannel coal in both benches, as indicated in the section obtained on the land of David Childers (fig. 12, section 12). North of Everman this coal is present over broad areas in the hills bordering Claylick, Oldtown, Lost, and Canes creeks and Fall Branch, but at no points were any openings in such condition as to enable the writer to measure or study the coal in detail. Near the mouths of these creeks the coal will be found between 200 and 300 feet above the bottom lands. Crandall[a] states that in the neighborhood of Raccoon, Buffalo, and Laurel furnaces, which are located in or near the northwest corner of this district on Raccoon, Claylick, and Oldtown creeks, respectively, this coal is present and usually 3 feet thick. There seems to be no reason why it should not be present in workable thickness over a considerable area west of Little Sandy River.

Character.—The sections in fig. 12 give an idea of the thickness of this coal and the number and character of its partings.

As will be seen from the sections the coal in some places consists of two and in other places of three or even four benches. Southeast of Grayson, at most of the country banks, it contains two benches (sections 2, 3, and 4, fig. 12), separated usually by a thin bone parting. The upper bench ranges from about a foot to 15 inches in thickness; the lower averages about the same. The coal varies in character in the two benches. At some points a cannel layer, from 1 to 2 inches thick, is present at the top of the upper bench, and at the George Armstrong bank (section 2, fig. 12) a 6-inch cannel layer was observed at the top of the lower bench. As a rule, the lower bench is more splinty and harder than the upper, but this is not invariably true. This bed averages about 2½ feet of excellent coal in the region southeast of Grayson. On Everman Creek (section 12, fig. 12) it contains more coal but also has a bad bony parting.

Where worked at Boghead and Hunnewell, the bed usually consists of three benches. The upper bench is ordinary lustrous bituminous coal and varies in thickness, being about 5 inches thick at Boghead and slightly less than a foot at Hunnewell. It is separated

[a] Kentucky Geol. Survey, vol. C, 1884, pp. 17–18.

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from the middle cannel bench by a bone or clay parting, which is from 1½ to 9 inches thick, being thicker near Hunnewell than at Boghead. The bottom bench is similar in character to the top bench. At Boghead it ranges from a foot to 14 inches in thickness, and at Hunnewell it is slightly thinner. It is separated from the middle cannel bench by a clay parting of variable thickness, this parting at Boghead reaching about 20 inches. The middle bench of cannel coal is the most valuable part of the bed at Boghead and Hunnewell. At the latter place it is about 15 inches thick. At the old Hunnewell workings 3 to 4 feet of cannel coal were reported as formerly mined, but no such thicknesses as this are now being worked. At Boghead

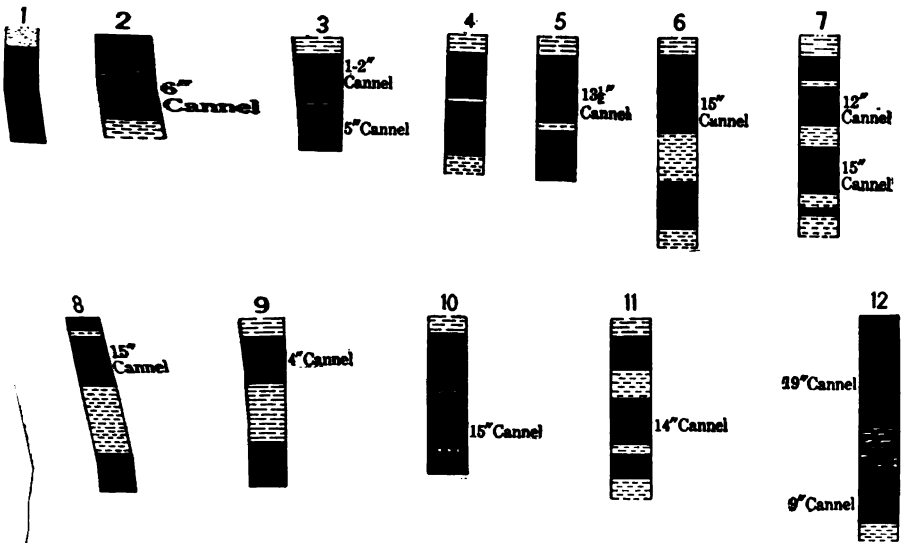

FIG. 12.—Sections of Lower Stinson coal (Kentucky No. 3). 1, Hill east of Grayson; 2, George Armstrong, 2 miles southeast of Grayson; 3, Robin Run, 2 miles southeast of Grayson; 4, John Crawford, Robin Run; 5, 6 (measured by G. H. Ashley); 7–9, Kentucky Cannel Coal Company, Boghead, Ky.; 10, 11, Kentucky Cannel Coal Company, Hunnewell mine; 12, David Childers, Everman Creek. Scale, 1 inch = 5 feet.

it is of about the same thickness, but at one point Doctor Ashley measured 27 inches of cannel, separated near the middle by a brown slate or clay parting 5 inches thick. George R. Hislop, of the Paisley Gas Works, Paisley, Scotland, has examined the cannel coal from the Boghead and Hunnewell districts. Of the former he says: "A sample of this coal representing the entire product of the seam is black and possesses a yellowish-brown streak and high luster. The fracture is slaty, coarse, and dull, with impressions of stigmaria, while in cross fracture it is conchoidal, with coatings of fire clay on the natural partings [joint planes presumably]. It is very compact and cohesive. On the fire it partially and slightly intumesces. The color of the ash is brown. It is well defined in stratification and is

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of very uniform density." His report on the Hunnewell cannel coal is as follows: "The coal is black, possesses considerable luster and yellowish-brown streak. The fracture is slaty, coarse, and partly semiscalariform, with numerous impressions of stigmaria. The cross fracture inclines to conchoidal, with deposits of calcium carbonate, clay, and iron bisulphide [pyrite] on the natural partings [joint planes]. It is massive, compact, and very cohesive. On the fire it does not intumesce. The color of the ash is pale brown. It is well defined in stratification and of very uniform composition and density."

Both the Boghead and Hunnewell cannels were analyzed and subjected to practical tests by Mr. Hislop, with the following results:[a]

Results of tests of Kentucky cannel coal.

	Boghead.	Hunnewell.
Specific gravity	1.175	1.215
CHEMICAL ANALYSES.		
Moisture expelled at 212° F.—per cent	1.21	2.75
Volatile matter—do	54.92	47.23
Fixed carbon—do	35.17	43.58
Ash—do	8.08	5.55
Sulphur—do	.62	.89
GASEOUS PRODUCTS.		
Gas per ton of coal at 60° F. and 30 inches barometer—cubic feet	14,752	14,260
Gas from 1 cubic foot of coal—do	541.37	483.44
Specific gravity of the gas—air 1,000	700	644
Hydrocarbons absorbed by bromine—per cent	15.33	14.25
Durability of 1 cubic foot by 5-inch jet flame—minutes	72	66⅝
Value of 1 cubic foot of gas in sperm—grains	915.60	843.12
Value of gas from 1 ton of coal in sperm—pounds	2,158.72	1,725.86
Illuminating power of gas in standard candles—candles	38.15	35.13
Sulphureted hydrogen (H_2S) in foul gas—per cent	1.25	1.75
Carbon dioxide (CO_2) in foul gas—do	2.50	2.50
Carbon monoxide (CO) in foul gas—do	7.00	5.50
Sulphur eliminated with volatile products—pounds	9.85	12.09
LIQUID PRODUCTS.		
Tar per ton of coal—gallons	20.34	20.12
Ammoniacal liquor per ton of coal—do	4.43	11.31
Strength of ammoniacal liquor—° Twad	4.00	3.00
Hygrometric water per ton of coal—gallons	2.71	6.16
Aqueous absorbent capacity of coal (determined by complete saturation)—per cent	1.35	2.80
SOLID PRODUCTS.		
Coke per ton of coal—pounds	972.83	1,108.35
Carbon in the coke—per cent	81.40	88.80
Ash in the coke—do	18.60	11.20
Sulphur in coke per ton of coal—pounds	4.08	7.84
Heating power of 1 pound of coke (water from boiling point into steam), pounds	11.18	12.20

In summarizing the properties of these cannels Mr. Hislop makes the following statements. Of the Boghead cannel he says:

This is an exceedingly rich cannel coal, yielding, as it does, an illuminating equivalent of 2,158.72 pounds of sperm candles per ton, while the coal contains a very small percentage of water and a moderate amount of sulphur. This

[a] Mr. Hislop's results were kindly furnished by Mr. S. G. Bates, of the Eastern Kentucky Railway.

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coal will be found a valuable one for the enrichment of inferior gases. Compared with main Lesmahagow cannel coal, represented by 100 (calculated on the basis of a production of 13,000 cubic feet of gas and 1,535.5 pounds of sperm per ton, and having regard also to the value of secondary products and the cost of purification of the gas), this coal is equal to 134.03.

Of the Hunnewell cannel coal he says:

This is a remarkably rich cannel coal; it is easily distilled, yields a large volume of 35.15 candle gas, and affords 9.9 hundredweight of coke per ton of medium quality, and quite available for heatings in furnaces or producers in combination with that from a bituminous coal. The coal contains about the average amount of sulphur, but a very small per cent of water. Compared with main Lesmahagow cannel coal, represented by 100 (calculated on the basis of production of 13,000 cubic feet of gas and 1,535.5 pounds of sperm per ton, and having regard also to the value of secondary products and the cost of purification of the gas), the coal is equal to 111.23.

In the Kentucky State mine inspector's report for 1899[a] there are some interesting comparisons given between other cannel coals of Kentucky and certain type cannels of Great Britain. The Boghead and Hunnewell cannel coal compares favorably with these, as will be seen from the following table:

Results of tests on cannel coals of Great Britain and Kentucky.

Location.	Gas per ton of coal (cubic feet).	Illuminating power of gas (standard candles).	Value of gas from 1 ton of coal (pounds of sperm).	Coke per ton of coal (pounds).
GREAT BRITAIN.				
Lesmahagow	13,201	34.52	1,562.00	1,019
Tyne Boghead	13,155	38.22	1,723.00	1,301
New Battle	12,461	35.34	1,509.00	983
KENTUCKY.				
Falling Rock	14,210	36.15	1,761.51	1,178
Bear Creek	14,680	41.24	2,069.00	995
Pineville Coal Co.:				
Boghead, Bell County	15,805	36.26	1,964.87	1,089
Willaford	15,835	44.55	2,418.68	995
Kentucky Cannel Co.:				
Boghead, Carter County	14,752	38.15	2,158.72	972.83
Hunnewell, Greenup County	14,260	35.13	1,725.86	1,108.35

With main Lesmahagow cannel coal as 100 (calculated on a basis of a production of 13,000 cubic feet of gas and 1,535.5 pounds of sperm per ton, and having regard also to the secondary products and the cost of the purification of the gas)—

Falling Rock cannel is equal to 112.07
Bear Creek cannel is equal to 137.11
Pineville Willaford cannel is equal to 148.81
Kentucky Cannel Company's Boghead cannel is equal to 134.03
Kentucky Cannel Company's Hunnewell cannel is equal to 111.23

The figures and analyses given above need hardly any comment. They indicate that the cannel coals of this district now worked by the

[a] See pp. 111–115 of that report.

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Kentucky Cannel Company are of the highest grade, the only hindrance in mining being the moderate extent of the territory underlain by them, in which respect they are like most other cannel coals.

DANLEYTON COAL.

Extent.—About 60 to 70 feet below the Hunnewell cannel coal is a bed which has been dug near Hunnewell and which outcrops on the hill on Cane Creek to the south. It also occurs in the hill 2 miles southeast of Grayson in a similar position, but locally at a greater interval below the Lower Stinson coal. About Hunnewell it is called the "clod seam," but it can not be positively stated that this is the "clod seam" of the Danleyton-Argillite district. The presumption is strongly in favor of their identity, but at the time of visit the opening at Hunnewell had fallen shut and the coal could not be seen. It is probable that the bed occurring near Hunnewell about 110 feet above the road is the Danleyton bed, as the two are characterized by an unusually massive underlying sandstone, and their distance, 100 feet below the base of the Homewood, is about the same. Near Hunnewell depot, about 30 feet below this bed, is a 10-inch coal which is probably not workable in this district, and on Turkey Fork a small 4- to 5-inch bloom was seen about the same distance above it. It is possible that these coals are those reported by Moore as occurring above Crandall's No. 1 coal[a] near Raccoon, Buffalo, and Laurel furnaces; hence the coal under discussion would properly be called No. 2 in the series of workable coals in this region. The difficulties in the way of correlating this coal bed with a coal bed west of Little Sandy River are many. East of Little Sandy River, on Culp Creek, Turkey Fork, and Cane Creek, the position and relationship of this coal are fairly clear with reference to the key rocks at the top of the Pottsville and at the base of the Allegheny. West of Little Sandy River the latter beds are generally absent from the hills, hence there is nothing definite to tie to except the Sharon conglomerate, which is somewhat scanty in its areal distribution.[b] It is believed, however, that this bed is not of any great importance west of Little Sandy River, a conclusion similar to that reached by Crandall.

Development.—East of Little Sandy River it has been opened on many farms near Argillite, but never has been shipped, so far as known. A description of the coal in this immediate region has been given on page 82. Farther south, in the hills along the Eastern Kentucky Railway, it is present, and has been opened on Turkey Fork and near Hunnewell,[c] 110 feet above the county road. The bloom of this coal shows on Black Branch of Little Sandy, east of Pactolus,

[a] Kentucky Geol. Survey, vol. C, 1884, p. 16. [b] Idem, p. 46. [c] See p. 82.

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and in general on all the county roads east and southeast of Grayson ascending the small creeks to their sources. On Upper Stinson Creek, near Stinson, a coal, presumably the Danleyton, lies 100 feet below the old workings of the Lexington Carter Company, which has been reported as working the Upper Stinson or No. 4 coal. This would make the coal come about 70 feet below the Lower Stinson cannel coal. It has been prospected at this point, and was reported 22 inches thick with two partings. A small coal 20 to 30 feet above it occurs here similar to that on Turkey Fork.

West of Little Sandy River the first coal bed of any importance above Crandall's No. 1 on Barrett Creek, being thus No. 2 of the Kentucky series, is found about 120 feet above the top of the Sharon conglomerate. It is approximately 60 feet, or slightly more, above Crandall's No. 1 of this region, and about the same interval, or slightly more (70 feet), below No. 3 coal. West of Little Sandy River this coal is usually present, but, like the first workable coal bed

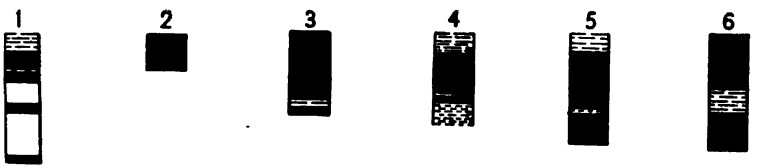

FIG. 13.—Sections of Danleyton and Barrett Creek coals. Danleyton coal: 1, 2, Everman Creek. Barrett Creek coal: 3, George Everman; 4, John Duley, Wolfpen Branch of Everman Creek; 5, A. J. Womack, Right-hand Fork of Everman Creek; 6, Near Samaria, Lost Creek. Scale, 1 inch = 5 feet.

above, it is opened at so few points that a good idea of its characteristics can with difficulty be obtained. Two openings on Everman Creek were visited, but the coal is so badly broken by bone partings as hardly to be valuable. Sections 1 and 2, fig. 13, show the coal as measured. It should be added that these sections were measured near the outcrop, where the true character of a coal is sometimes obscured. At the bank of David Childers, where the second section was obtained, it was reported that there are 3 feet of coal. At the time of the writer's visit in October the owner had not begun to dig his winter supply of fuel and the inner workings were not accessible. It is questionable whether this bed will add much to the coal resources of this district.

BARRETT CREEK COAL (NO. 1).

Extent and development.—The next lower workable coal corresponds to No. 1 of the Kentucky Geological Survey. In Crandall's general section this coal is placed about 40 feet above the top of the Sharon conglomerate, which is practically the same position as is

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given to it in the writer's general section. (See Pl. IV, p. 28.) It is about 60 feet below the next higher workable coal, but its position with reference to the Sharon conglomerate where this bed is present will serve in most places to identify it. Crandall has stated that "it appears to be the equivalent of the Jackson Shaft coal in Ohio."[a] This is perhaps placing the equivalent of that Ohio coal a little too high in the Kentucky series, for the coal associated with the black shale lying within the Sharon conglomerate on Everman Creek appears to contain a fossil flora similar to that of the Jackson Shaft coal of Ohio, and hence is probably more nearly the stratigraphic equivalent of the Ohio coal than the bed 50 to 60 feet above the top of the Sharon.

The coal has been developed on Barrett Creek at many points. It has also been opened on Wolfpen Branch and Righthand Fork of Everman Creek. On Canes Creek, about 2½ miles west of Hopewell station, it has been opened by Marion Smith, and though reported thin it is of excellent quality for smithing purposes. On Lost Creek near Samaria it has been opened on the land of Mr. Stevens. Its bloom also shows on Oldtown Creek and its north fork. It is present in all the hills in this district west of Little Sandy River and will be found in workable thickness, at least for local use, over a broad area.

East of Little Sandy the coal is not so extensively distributed above drainage level owing to the eastern dips. Between Argillite and Laurel it appears as a small bloom at a few points on the county road along the Eastern Kentucky Railway, but has not been opened, so far as known. It is probably this coal which is opened at a few points on Cane Creek south of Hunnewell, where it is about a foot thick.

Character.—The sections in fig. 13 give an idea of the thickness of the Barrett Creek coal. The sections show that it is comparatively thin, and, though usually of workable thickness, at many points it falls below what might be regarded as commercial requirements for this region, namely, 2 feet. It consists at most points of two benches, an upper carrying from 1 to 2 feet of coal, and a lower, usually thinner, ranging from 2 inches to a foot. It has near its base a clay, shale, or bone parting, in places 6 inches thick. Crandall[b] reports this coal bed as being at Raccoon furnace, just north of the northwestern corner of this area, about 30 inches thick; near Buffalo furnace on Claylick Creek 3 feet, with a clay parting near its middle; and near Hopewell station 3 feet. The coal is, for the most part, of the soft bituminous type, but in some places the lower bench is hard and splinty. Mr. Ashley observed a thin cannel bench at the top of the upper bench on Lost Creek. The coal is regarded as of very high grade for local and smithing purposes.

[a] Kentucky Geol. Survey, vol. C, 1884, p. 11. [b] Idem, pp. 11–13.

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LOWER COALS.

About 50 to 60 feet below the Barrett Creek coal occurs a single small coal bed and in places a second coal a few feet still lower. These are thin beds lying near the top of the Sharon conglomerate, and possibly the lower coal is within the stratigraphic equivalent of the Sharon. Where only one of these coals is present it is impossible to tell which of the two it is. One of these coals was exposed in an excavation below the post-office at Grayson and appears at several points on the county road south of the town. It was opened in the bed of Town Branch to the west. It rests directly on a thin bed of quartz or quartz-like micaceous sandstone, not over 5 to 6 feet thick, which is a fairly persistent stratum in the immediate neighborhood of Grayson. The two coals near the bridge over Little Sandy River, east of Grayson, are probably equivalent to the coals just mentioned south of the town. They also are too thin to work at this point. In the valley of Upper Stinson Creek directly east of Grayson two coals show just at the foot of the hill to the left of the road going east, and at the edge of the meadow the lower of these coals is 20 inches thick and has a bone floor and a shale roof. The fossils collected by Mr. White were not distinctive. Near the north end of the tunnel of the Eastern Kentucky Railway, south of Hopewell, this coal shows, but here also is too thin to work. The coal was also noted east of Pactolus on the hills near Black Branch, where it is too thin to export, though it is of some local importance.

The lowest coal of importance in this region occurs within the Sharon conglomerate itself. The dual character of this sandstone member is shown on Everman Creek near its junction with Wolfpen Branch, where a black shale is present 15 to 20 feet below its top. In places this shale is coal bearing, and the thin coal found in this position at the farm of John Duley farther up Wolfpen Branch is regarded by David White as the stratigraphic equivalent of the Jackson Shaft coal of Ohio and the Sharon of Pennsylvania. This coal has also been worked on Barrett Creek almost at water level. Opposite the residence of L. D. O'Roarke 6 inches of coal shows. The coal has been opened farther up the creek, where the county pike turns over the hill to Everman Creek. On Canes Creek the Sharon is very massive, and this coal again appears but is only 6 inches thick. Like the other coals below No. 1, this is too thin to be commercially valuable.

DISTRICT TRIBUTARY TO SOUTHERN TERMINUS OF EASTERN KENTUCKY RAILWAY.

EXTENT.

The district, including approximately the southwestern quarter of the quadrangle, contains in its northern part the southern 8 miles of the Eastern Kentucky Railway, passing through Willard and ending

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at Webbville. Nearly all the lumber, staves, and country merchandise shipped out of this region go via this railroad, hence the reason for applying the above title to it. It includes all of Elliott County within the Kenova quadrangle, the extreme western part of Lawrence County, and a very small portion of southern Carter County.

GEOLOGY.

STRATIGRAPHY.

The Conemaugh, Allegheny, and Pottsville formations are represented in this district. In the northern part, east of Willard, in the deepest part of the basin, the surface is entirely made up of Conemaugh rocks. Immediately west of Willard and in a few isolated areas on the hilltops west of Dry Fork, Conemaugh rocks outcrop. A good idea of the character of this group of rocks may be had by climbing the hill east of the mouth of Thompson Fork or ascending Lost Branch, Belle Trace Creek, Beetree Fork, or Straight Creek east of Denton. Between 300 and 400 feet of the Conemaugh is shown, consisting of sandstones, shales, limestones, iron ore, and coal streaks. The coal in this formation is too thin and pockety to be of any importance except locally. There are at least three or four thin beds of limestone, the most persistent being a siliceous bed 4 to 5 feet thick lying near the base of the Conemaugh, about 180 feet above the Coalton coal as measured at Willard. This limestone and possibly the higher beds might be used locally as a source of fertilizer. The lower limestone probably corresponds to one of the Cambridge limestones of the Ohio geologic section. There are some rather massive sandstones scattered through the group of rocks, notably in its lower 100 feet. Some of the sandstone appears to be good enough for building purposes.

The Allegheny formation is in this district, as usual, the most important from an economic standpoint. A section measured west of Willard gives a fair idea of the sequence of the coal beds in it. It must not be understood that all the coals observed in this section will appear in the Allegheny, in other parts of this district, for the formation is somewhat variable. As an instance of this, on the west side of the hill where the following section was measured the formation had thinned somewhat, and, though the exposures were fairly good, fewer coals were found in it.

Section in hill west of Willard, Carter County.[a]

Top of hill.	Feet.
Sandstone, massive, and sandstone débris	45
Limestone, massive, drab, fossiliferous (Cambridge limestone)	4–5
Partly concealed with sandy débris and sandy shales	60

[a] This section represents the average of two distinct barometric determinations.

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	Feet.
Sandstone, massive, white to light brown	25
Coal bloom No. 9 (top of Allegheny).	
Fire clay	2–3
Shale, sandy, and shaly sandstone	20
Coal bloom No. 8.	
Concealed and sandy	15
Limestone, yellow	1½+
Shale, drab	15
Coal (workable) No. 7.	
Sandstone, laminated	20
Ore, limestone.	
Concealed	10
Coal bloom No. 6.	
Shale (fire clay at top)	15
Coal, two small blooms 6 inches apart.	
Shale and fire clay	20
Coal bloom No. 5.	
Sandstone, laminated	10
Sandstone, massive (Homewood)	30
Coal bloom (coal has been worked).	
Fire clay.	
Sandstone and shale	15
Coal bloom (coal has been worked).	
Sandstone	10±
Base of hill.	

The Allegheny formation ranges in this district from about 120 feet to possibly 200 feet in thickness. In places it may even be thinner than 120 feet. It includes at least three valuable coal beds workable at different points, at least one valuable fire clay, and iron-ore deposits, but the bulk of it, as usual, is composed of sandstone and shale. It forms the surface in a more or less irregularly curved strip, which follows the direction of the contour lines from Straight Creek to the southwest and then trends southeastward to the limits of this district. Many of the hilltops west and south of the main Allegheny belt are formed by this group of rocks. Roughly, it covers about one-third of the surface in this district.

The lowest formation present in this district is the Pottsville. In places it is between 500 and 600 feet thick, and it is prevailingly sandy throughout, though containing some shale beds. Its two most prominent members are the Homewood sandstone near the top and the Sharon conglomerate near the base, each of which attains in many places a thickness of 100 feet of very massive rock. The Homewood member is broadly distributed; the line or outcrop of its top, if represented on the map, would coincide very closely with the red line which indicates the outcrop of the fire clay associated with the Vanport ("Hanging Rock") limestone. The Sharon conglomerate appears in the valley of Little Sandy River, along Brushy, Hood, and Upper

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and Lower Laurel creeks, and on Field Branch. Roughly, this formation covers perhaps about one-half of the surface in this district. The Pottsville formation is of importance economically, containing coal beds locally workable and at some points cannel coals. It also contains iron ore, fire clay, and sandstone of value. These beds are described in detail under the appropriate headings.

STRUCTURE.

The structure of this district is more involved than that of any of the districts previously described. The synclinal trough which traverses the quadrangle from northeast to southwest begins to die out in the vicinity of Willard and Webbville. Between these two towns the basin rises sharply toward the west. About Webbville and to the south the beds are generally inclined to the north and northeast; about Willard and to the north the pitch to the southeast is very sharp. Near Daniels Creek the Homewood sandstone thickens abruptly toward the west, giving rise to a slight dome in the rocks lying on the top of this sandstone and to a slight depression or basin as it becomes thinner again toward Cherokee Creek. West of Cherokee Creek the structure is not marked, though there is a gradual westward rise of the beds. About the town of Blaine the beds dip more sharply than at any point in the area, and at the bridge over Hood Creek apparent dips range from 11° to 24° in a nearly due north direction. Mr. Ashley discovered two minor faults in the hills east of Blaine, but they are of small magnitude, and a short distance away the beds can be traced continuously.

THE COALS.

CONEMAUGH COALS.

The blooms of a few coal beds show wherever any considerable section of the Conemaugh formation is exposed. A small coal bed occurring within 10 feet of the bottom of the Cambridge limestone appears to be fairly persistent and has been dug for local use near the head of Belle Trace Creek, Jordan Fork, and Straight Creek. This coal is not commercially valuable.

ALLEGHENY COALS.

UPPER COALS.

The two upper coals of the Allegheny formation outcrop at many points in this district, but apparently are too small for exploitation. In the section in the hill west of Willard (pp. 96–97) these two coals appear, the No. 8 or Hatcher coal about 32 feet above the Coalton, which has been dug into along the roadside, and the Zelda or No. 9

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coal about 25 feet higher up. The intervals in this vicinity are apparently much less than those prevailing along Ohio River. At the head of Thompson Fork and the tributary flowing into it from the north the Zelda coal is thick enough to be worked for local use, and the following section was measured near the head of the main fork. (See also section 1, fig. 14.)

Section of coal No. 9, near head of Thompson Fork.

	Inches.
Sandstone.	
Bone	8
Coal	26
Fire clay.	

COALTON COAL (NO. 7).

Geologic position.—In the northern part of the district the Coalton coal is of considerable economic importance. Its occurrence here is merely the southwestern continuation of this coal in the Chesapeake and Ohio Railway district. About Willard it is found at 65 to 90 feet above the top of the Pottsville. The former measurement was obtained in the hill west of the town; the latter is the more usual interval. The coal bed occurs 50 feet above the fire clay at the Vanport limestone horizon at the north end of the town, about 30 feet above the Winslow coal, and 180 feet below the Cambridge limestone. Owing to the persistence and broad distribution of the Cambridge limestone it will serve as an excellent base from which may be calculated the depth below the surface of the Coalton coal well up on the headwaters of the numerous smaller creeks flowing into Little Fork. It is quite possible that deviations from the interval measured at Willard will be found.

Extent and development.—About Willard and north of Webbville the Coalton coal has been opened and worked at many places. In this vicinity it outcrops well down in the hills so that tipples may be conveniently run out to the main line of the Eastern Kentucky Railway or to short spur tracks. It outcrops in the hills between Straight Creek, Belle Trace Creek, and Lost Branch, disappearing below drainage level on Lost Branch near the mouth of Crooks Creek. A large body of valuable coal still remains untouched in these hills, and east of the points where it goes below drainage level no shafts have ever been sunk to reach it. Numerous country banks show this coal to be of fair thickness to points about a mile above the mouth of Belle Trace Creek and about a mile above the mouth of Lick Branch, west of Willard. South of Webbville the coal is present in the hills along Caney, Dry, and Equal forks, rising to the south. It has never been opened in this region. West of Dry Fork and Cherokee Creek the rise is so great that the coal is found only

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near the tops of the hills, and consequently in small bodies. It is found in the ridge between Equal Fork and Blaine Trace Branch and to the west in the ridge between Little Fork and Blaine Trace Branch, where 3½ feet of cannel coal is reported; it is present also in the hills north of Hurricane Creek. West and northwest of Willard the beds rise so steeply that the Coalton coal is present only here and there in the tops of the highest hills, as, for instance, at the head of Field Branch and Johns Branch.

The center of development of this bed lies about Willard and Webbville and at or near the mouth of Lost Branch, Lick Branch, and Belle Trace Creek. The only large commercial operation on this bed is that of the Eastern Kentucky Railway on Lost Creek.

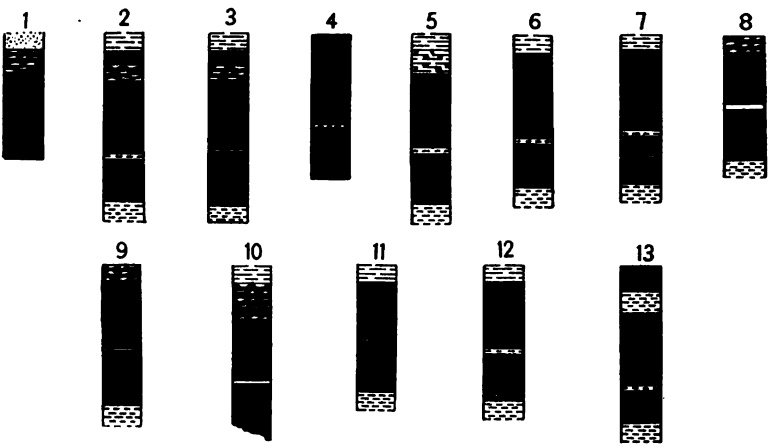

FIG. 14.—Sections of Zelda and Coalton coals. Zelda: 1, Head of Thompson Fork. Coalton: 2, East Kentucky Railway mine, Partloe (Mayapple post-office), Lost Branch; 3, James H. Williams, Lost Branch; 4, A. E. Fauson, Lost Branch; 5, southern part of Willard; 6, east of Willard; 7, east of Willard (Ashley); 8, 9, mouth of Belle Trace Creek; 10, on Little Fork, north of mouth of Lick Branch; 11, near mouth of Lick Branch, west of Willard, on small tributary from the north; 12, Lick Branch, west of Willard; 13, head of Davies Branch (Ashley). Scale, 1 inch = 5 feet.

This company formerly mined this bed on an extensive scale south of Willard, but at present all the old mines are shut down. From the economic map an idea of the extent of this coal above drainage may be readily obtained.

Character.—The thickness of this coal may be seen from the sections in fig. 14. It will be noted that the coal shows great uniformity in its division into benches and also in the thickness of these benches, and, though not indicated in the figures, the character of the coal in the different benches is also uniform. On Lost Branch and at the head of Davies Branch where measurements were made three benches are developed (sections 2, 3, and 13, fig. 14.) The top bench is from 4 to 7½ inches thick and is not worked. In the immediate vicinity of Willard only two benches were noticed (sections 5, 6, and

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7, fig. 14). The upper bench is about 2 feet thick, grading into bony coal at the top; the lower bench is usually a little more than a foot thick and is separated from the top bench by an inch or two of clay or shale. Near the mouth of Belle Trace Creek the upper bench seems to thin considerably and to range where measured from 15 to 20 inches in thickness (sections 8 and 9, fig. 14), and the lower bench, which is about 16 or 17 inches thick, is comparable in thickness with this bench near Willard. On Lick Branch, west of Belle Trace Creek, the sections obtained are about the same as those seen on the latter stream. The total thickness of these two worked benches rarely reaches 45 inches and averages most commonly about 3½ feet. From 40 to 45 inches of workable coal in the upper two benches may therefore be considered a maximum for this bed. From these thicknesses it thins out to nothing at some places where rolls in the roof and horsebacks occur.

The roof is as a rule fairly massive shale of variable thickness, usually capped by a very massive sandstone. The immediate roof is generally bony coal. The foreman of the Eastern Kentucky Railway mine at Partloe reports that the roof gives little or no trouble. Falls are rare, but posts are used. The floor is clay, but so far as known it is not mined for economic purposes.

The coal is bituminous. The upper bench is soft and full of charcoal partings; the lower bench is hard and splinty. Both are worked and shipped, the bone and clay partings being picked out by hand. Mining is fairly difficult.

The composition of this coal is illustrated by the analyses given on page 71. These figures are for the most part those of coals collected in the region about Rush, but analyses 11 and 12 represent samples collected from Lost Creek and west of Dry Fork near Willard and may be taken as typical of the coal in this vicinity. The application of this coal to iron making has been treated at some length in the discussion of its chemical character in the Chesapeake and Ohio Railway district (pp. 70–73) and will not be considered further here. It is not a coking coal, the output of the Eastern Kentucky Railway mine at Partloe being used exclusively along the railway for steaming and domestic purposes, for which it is admirably adapted.

WINSLOW COAL (NO. 6).

Extent and development.—The next lower coal corresponds with coal No. 6 of the Kentucky series and has been described in the section on the Chesapeake and Ohio Railway district under the name Winslow coal, owing to its fairly extensive exploitation at Winslow. Here, as in the district just referred to, it occupies a position between the Coalton coal above and the Vanport ("Hanging Rock") lime-

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stone below. In the district north of Daniels Creek, Lawrence County, and on the ridges east and west of Blaine Trace Branch and at the head of Ison Creek, Elliott County, it is usually from 45 to 60 feet above the Vanport limestone, and as this limestone is very near the top of the Pottsville or Homewood sandstone, the same interval may serve also when the coal is referred to the latter horizon. About Willard, near the fire-clay mines in the northern part of the town, the smut of this bed was noted about 20 feet above the fire clay associated with the Vanport limestone and about 30 feet below the Coalton coal. West of the town it is about the same distance below this coal and above the Vanport limestone. Its identification in and about Willard is easy, as the red limestone ore overlying the Vanport limestone has been extensively worked at this place in the past. The coal is broadly distributed.

Though it outcrops in all the hills about Willard, it has never been worked and nothing can be stated definitely as to its character. It is probably too thin to be of any great value. Its bloom was noted in the hills skirting Dry Fork, Equal Fork, and Blaine Trace Branch. At the head of Equal Fork and Perkins Branch it is of workable thickness, and at a few country banks the coal is being opened. In this locality it will repay careful prospecting, for the underlying coal also is a most valuable bed, and should the Eastern Kentucky Railway be extended southward from Webbville to Blaine it would pass near enough to the heads of Perkins Branch and Equal Fork to make the coal in this locality of probable commercial importance. South of this point very little is known about it, but it should be found in the hills northeast of Canes Creek and in the ridges bordering Irish and Cherokee creeks. In the hills north of Daniels Creek and west of San Branch it has been opened and worked in a small way. On Brush Creek, south of the Elliott-Lawrence county line, this coal has been opened by J. Porter and is sufficiently thick to be worked in a local way. In the hills north of Mount Savage it seems also to be fairly persistent. At the head of Ison Creek, west and northwest of Stephens, Elliott County, a cannel coal is found about 50 to 60 feet above the top of the Pottsville and is referred to this horizon. It has been opened by L. A. Clark, W. B. Boggess, Isom Ison, and others in this region. This is the only known occurrence of cannel coal at this horizon. Northwest of Willard, near the hilltops at the heads of Johns Branch and Field Branch, this coal is present, but the area which it covers is small, owing to the steep rise of the beds to the west.

Character.—The sections of this coal obtained are so few in number that no reliable generalizations can be made regarding its physical character. Neither can it be stated that their paucity is an index of the thinness or poorness of the coal, for about the head of Equal Fork

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and Perkins Branch and in the hills west of Dry Fork a considerable body of this coal exists in workable thickness. The area underlain by it is fairly comparable with that underlain by the Vanport limestone, which is indicated by the red line on the economic map (Pl. I), but as the coal lies somewhat higher in the hills its area will be slightly smaller than that of the limestone. As judged by sections 1 and 4, fig. 15, this coal is fairly comparable in this immediate locality with the same bed in the Chesapeake and Ohio Railway district. It carries three benches, separated by thin partings of bone or fire clay. The two top benches are soft bituminous coal; the lowest bench is hard splint. In this immediate territory the roof is shale and the floor clay. Little is known about the coal to the west, except along the edges of the quadrangle west and northwest of Stephens and north of Fielden. In this region the coal is largely cannel. Sections obtained here also show three benches (section 3, fig. 15). This coal has been opened in the hill south of Brush Fork by L. A. Clark

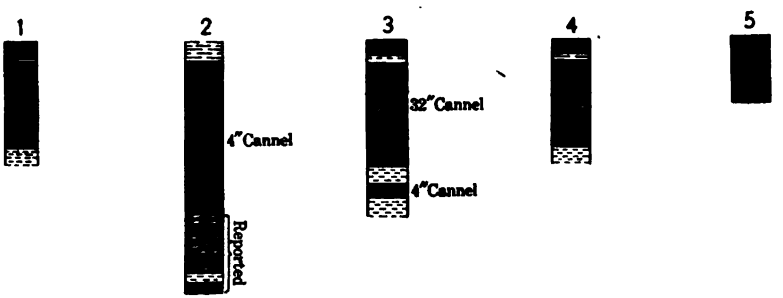

FIG. 15.—Sections of Winslow coal (Kentucky No. 6). 1, W. M. Clark and A. C. Campbell, head of Perkins Branch; 2, 3, head of Ison Creek (Ashley); 4, Dry Fork; 5, ridge between Equal Fork and Blaine Trace Branch. Scale, 1 inch = 5 feet.

and W. B. Boggess, and at Mr. Clark's bank it was reported 4 feet thick. Nothing is known of its character outside of the inconsiderable area bounded by Little Fork, Brush Fork, and Critches Creek, and in this district the acreage of cannel coal is not large, owing to its position very near the hilltops. It is, however, a valuable cannel coal, which will be worked in the future when cheaper transportation facilities are obtainable.

CAT CREEK COAL (NO. 5).

Extent and development.—The next lower coal is the most important coal in this district. It reaches its greatest thickness along Dry and Caney forks and Cherokee Creek and in the hilltops northwest of Willard, at the head of Johns Branch. It is the lowest coal in the Allegheny formation in this area and closely underlies the Vanport limestone. If it were correlated with one of the Pennsylvania or Ohio coals it would probably correspond to either the Brook-

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ville or the Clarion; certainly not with any of the Kittanning coals, for these are all above the Vanport limestone. In this district little difficulty will be experienced in identifying this coal bed. Its position 20 feet or so below the Vanport limestone and on or near the top of the Homewood sandstone, which along Cherokee, Dry, and Caney creeks is very massive, should serve at once to locate it. This coal bed without doubt corresponds to coal No. 5 of the Kentucky Geological Survey. Its occurence in this district may with a fair degree of certainty be regarded as the western continuation of the coal occurring on Cat Creek, and so this name is used in this district. It has been carefully prospected in the hills lying about the head of Cherokee Creek, Dry Fork, and Equal Fork, and along Caney Fork well toward its mouth. It is present in the hills bordering Dry Fork and dips rather steeply to the north, disappearing below

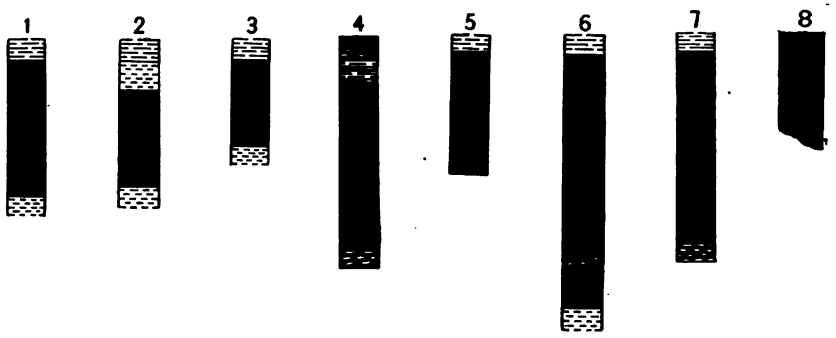

FIG. 16.—Sections of Cat Creek coal (Kentucky No. 5). 1, J. C. Webb, Caney Fork; 2, James Bryant, Caney Fork; 3, Henry Campbell, Caney Fork; 4, J. A. Young, head of Cherokee Creek; 5, James Wheeler, ridge east of Backbone; 6, 7, James Adams, head of Johns Branch; 8, J. C. Johnson, near head of Equal Fork. Scale, 1 inch = 5 feet.

drainage level before Webbville is reached. The same dip in the beds also causes its disappearance below drainage level before it reaches the mouth of Caney Fork. It is present in the ridge between Blaine Trace Branch and Equal Fork, and where seen near Backbone it is a thick coal bed of excellent quality. Its position is indicated by a bloom at many places in the ridge lying still farther to the west between Little Fork and Blaine Trace Branch. The southernmost point where its bloom was seen is in the hills just northeast of Blaine, but nothing is known of its character here. A large territory is underlain by this valuable coal in the region about Caney Fork, in the hills along Dry Fork and Cherokee Creek, in the hills between Equal Fork, Blaine Trace Branch, and Little Fork, and possibly south of Perkins Branch. Northwest of Willard this coal bed also appears in the hills and has been opened at a few places at the head of Johns Branch. At the banks of James Adams (sec-

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tions 6 and 7, fig. 16) and John W. Barber the coal is comparable in thickness with the coal seen at the head of Cherokee Creek.

No attempt has been made to develop this coal on a commercial scale, though the construction of a spur track up Dry Fork is apparently a simple matter and such a spur would tap a large body of coal.

Character.—Measured sections of this coal are given in fig. 16. The sections given for this coal on Caney Fork were measured in small country banks and very near the outcrop and it is possible that they may not represent the true thickness of the coal. As seen on Caney Fork, the coal will probably average between 3 and 4 feet in thickness. As a rule the roof of the coal here is shale.

At the heads of Dry Fork and Cherokee Creek and to the west at the heads of Perkins Branch and Equal Fork the coal attains its greatest development in this district. At the J. A. Young mine, on a small creek entering the head of Cherokee Creek from the east, more than 4 feet of excellent clean coal was measured (section 4, fig. 16). From this mine a large block of coal representing the entire thickness of the main workable bench was taken to the Louisiana Purchase Exposition at St. Louis. At some points in the mine a lower bench, less than 1 foot in thickness, is reported, but this is not everywhere present. As a rule the roof is shale and the floor is bone passing into clay. In the ridge between Equal Fork and Blaine Trace Branch, a short distance east of Backbone, Mr. Ashley measured 38 inches at a bank owned by James Wheeler. It was reported that the usual thickness is 3½ feet. Mr. Ashley also measured 30 inches of coal in the ridge west of Equal Fork at the bank of J. C. Johnson, but 3 feet were reported to him.

The Cat Creek is a bright, lustrous bituminous coal, containing streaks of harder coal with probably some splinty layers. Without much doubt it will serve well for steaming and domestic purposes, but its efficiency as a coking coal has not yet been determined. It was used to supply the engine running the drill which bored a hole 2,000 feet deep near J. A. Young's residence at the head of Cherokee Creek, and it gave splendid satisfaction as a steam generator. From the fact that it separates into rectangular blocks of fair size and may be removed from its position in blocks the thickness of the entire main bench, it may appropriately be classed among the block coals. The following analysis was made by the Kentucky State chemist:

Analysis of coal No. 5 from J. A. Young's bank at head of Cherokee Creek.

Moisture	7.04
Volatile matter	36.88
Fixed carbon	53.72
Ash	2.36

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The analysis shows this coal to be of very high grade. The moisture is rather high, but ash is low. No sulphur is given, but this constituent was probably not determined, as it is quite certain that some sulphur is present.

Economic aspects.—The marketing of this coal is an important consideration. The Eastern Kentucky Railway has extended its line as far south as Webbville, but under present conditions this does not materially help the exploitation of coal at the head of Dry Fork and Cherokee Creek. To get this coal to market it will be necessary to extend the railroad as far as the head of Dry Fork at least. This can be easily and cheaply accomplished, owing to the easy grade and absence of sharp curves on Dry Fork. Should the road be continued to Cherokee Creek, the divide would probably be tunneled. It may not be expedient to do this, for the bulk of the coal could be readily tapped by spur tracks from the main line up Dry Fork. It is generally understood that the Eastern Kentucky Railway proposes to extend its tracks as far south as the town of Blaine.

POTTSVILLE COALS.

UPPER STINSON COAL (NO. 4).

Geologic position.—In this district the Upper Stinson coal, though widely distributed, can not be classed among the important beds except locally. It has been stated that it is the highest coal in the Pottsville formation and that it occurs directly below the massive sandstone member (Homewood sandstone) forming the top of this formation. Its position below the top of the Homewood sandstone and hence below the Vanport ("Hanging Rock") limestone is variable, depending on the thickness of the Homewood, which is also variable.

About Willard the Homewood sandstone is massive, though not more than 30 to 40 feet thick. In the hills bordering Dry Fork and Cherokee Creek it seems to be less than 50 feet thick, but to the west it is thicker, at many places from 80 to 110 feet. At the heads of Justice, Leadenham, Hilton, and Wells branches and farther south in the region about Backbone and north of Stephens it is 110 feet or even thicker. South of Backbone and Stephens it becomes thinner again. At the head of Wiley, Collier, and Knob branches this member is unusually massive. Thus the Upper Stinson coal occupies a variable position with reference to the top of the Homewood sandstone, occurring usually from 40 to 110 feet below it.

Extent and development.—The coal is broadly distributed in this district. In its northern part it is present in the hills at the heads of Huff Creek and Field and Johns branches. An opening belonging to Silas Walker west of the head of Field Branch showed this coal

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to be of workable thickness. The section measured is given in fig. 17 (section 1). On most of the waters of Blaine Creek and Little Fork the bloom of this coal bed shows, but few openings on it were observed, the presumption being that as a rule it is not workable. On Hilton Branch a coal regarded as the equivalent of this coal appears to be chiefly cannel. About a mile from the mouth of the branch on its north side, about 200 feet above the creek bed, there are two openings. At the one nearer the mouth of the creek, on the farm of Elijah Sturgill, 9 inches of coal were seen with more below, capped by 6 inches of shale overlain by very massive sandstone. Mr. Sturgill, jr., reports the usual thickness of the cannel coal to be about 3 feet with less than a foot of bituminous coal overlying it. Farther up the creek, on the land of William Corey, a section of the same bed was measured, and is represented in section 3, fig. 17. Mr. Corey reports

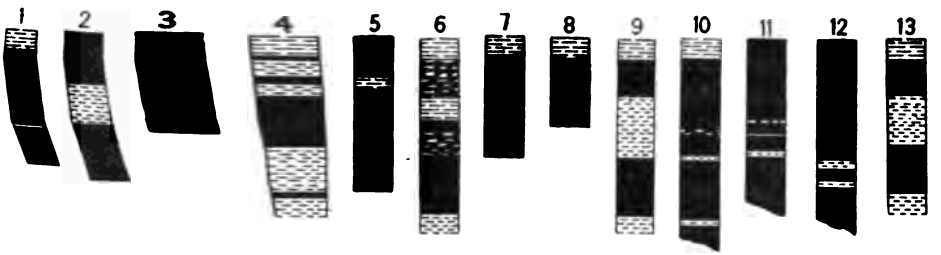

FIG. 17.—Sections of Pottsville coals. Upper Stinson coal (Kentucky No. 4): 1, Silas Walker, west of head of Field Branch; 2, northeast of Sarah (Ashley); 3, William Corey, Hilton Branch. Lower coals: 4, F. E. Holbrook, Right Fork of Blaine Creek; 5, A. T. Boggs, Right Fork of Blaine Creek (reported); 6, W. H. Lyons, Right Fork of Blaine Creek; 7, Levi Kitchen, Dry Fork; 8, head of Leadenham Branch; 9, J. N. Sparks, Halton Branch, west of Fielden (Ashley); 10, 11, 12, Robert Green, Halton Branch, west of Fielden (Ashley); 13, J. M. Green, head of Little Fork, west of Sarah. Scale, 1 inch = 5 feet.

29 inches of cannel as a maximum. The cannel coal was not seen north or south of Hilton Branch.

The coal in this district, aside from the cannel phase just described, is of the usual soft, lustrous character, in many places containing bands of harder splint.

LOWER COALS.

The next lower workable coal in this district occurs in most places 160 feet below the top of the Homewood sandstone. It will be found in this position along Right Fork of Blaine Creek and on the streams which flow into it from the north and on the headwaters of Little Fork. Possibly the coal opened by R. T. Berry east of the town of Blaine belongs here also. It is a question whether this coal can be regarded as the exact equivalent of the Lower Stinson or Torchlight bed, but in the sense of its being the second workable coal in the Pottsville, counting from its top, it may be called for convenience

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No. 3. A section obtained in the ridge south of Rockhouse Branch showed five small coal beds lying between the coal under discussion and what is probably the top of the Pottsville formation. The occurrence of so many coals between the so-called No. 3 in this district and the top of the Pottsville is probably not very widespread, although it is quite probable that there is more than one coal in this interval. These intermediate coals may be locally workable. The conditions here present a strong argument against adhering strictly to a system of numerals in correlating coal beds over broad areas.

This coal, as has been said, occurs 160 feet below the top of the Pottsville formation on Right Fork of Blaine Creek. In the northern part of this district it will be found at a less distance from this horizon, and at the head of Field Branch the interval can not exceed 80 to 100 feet. Here this coal is not of workable thickness, but it is of more than ordinary interest from the fact that it consists largely of cannel. A section measured on the farm of Silas Walker showed 12 inches of cannel underlain by 8 inches of ordinary soft, bituminous coal. South of this place a coal, probably the equivalent of this bed, has been opened at the head of Leadenham Branch by Jackson Wilcox. The coal here has a shale roof and measures approximately 2 feet (fig. 17, section 8). Near Backbone and Stephens it is found near the bed of the creek and has been worked on a small scale for local supply. No measurements of the coal were obtained in this vicinity. On Dry Fork, about 2 miles south of Webbville, it has been opened by Levi Kitchen near the bed of the creek, and the section shows about 2½ to 3 feet of coal containing small partings of bone in its lower half (fig. 17, section 7). This coal is highly esteemed in the immediate neighborhood for smithing and domestic purposes. South of Cherokee it will be found near road level above the massive sandstone outcropping near the bridge over the creek. It has been opened at several points in the vicinity of Fielden and Sarah, where it is called the "mud seam." On Canes Creek, Rockhouse Branch, Knob Branch, Equal Fork, and in the vicinity of Willard sections obtained from this coal show it to be badly broken, and, though an important source of supply for local purposes, it is a question whether a coal with so many partings can become of commercial importance in the near future. Except where the coal is of the cannel type, as observed near the head of Field Branch, in Carter County, it is of the same character as the rest of the coals in this district—namely, partly splint and partly soft, lustrous bituminous coal.

The Barrett Creek coal, or No. 1 of the Kentucky series, has been opened at a few points on Deer Creek, northwest of Willard, and near Rosedale. The coal on Deer Creek shows at the two points where measured a somewhat better section than it does on Barrett Creek. (Compare fig. 18, sections 1 and 2, with fig. 13, sections 3,

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4, 5, and 6.) Its position, about 60 feet above the top of the Sharon conglomerate, which is prominent along Little Sandy River in this region, serves to identify it. At Mrs. Rebecca Tackett's this bed shows 3 feet of clean, bright, lustrous coal with no partings, but at the bank of William Herbelan, well up on the east fork of Deer Creek, though the coal is still about 3 feet thick, it contains a band of bony coal near its top (section 1, fig. 18). The coal opened at the mouth of Field Branch is referred to this horizon. It probably belongs in the group lying close to the top of the Sharon conglomerate, as is indicated by the section obtained in crossing the ridge from Deer Creek to Little Fork. This section again illustrates the objections raised in this bulletin to numbering coals. On the west side of this ridge at least ten small coal beds appear, any one of which theoretically may be thick enough to be commercially valuable at some place. On the east side of the ridge seven coal beds were counted, the lowest of which is the one referred to above as outcropping near the mouth of Field Branch. This coal has been opened by Walter Field, Robert Rucker, and others, the openings being at

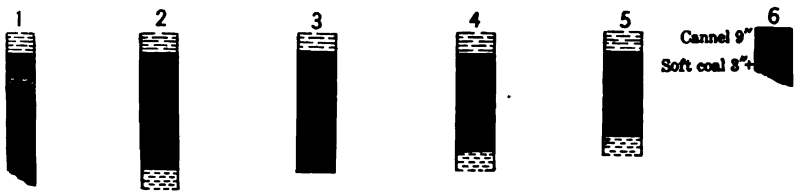

FIG. 18.—Sections of Barrett Creek coal. 1, William Herbelan, Deer Creek; 2, Mrs. Rebecca Tackett, Deer Creek; 3, Walter Field, Field Branch; 4, Robert Rucker, Field Branch; 5, R. T. Berry, Blaine; 6, J. W. Sparks, Sarah. Scale, 1 inch = 5 feet.

the base of the hills, but a few feet above the flood plains. At Mr. Rucker's coal bank about 2½ feet of excellent coal appears between a shale roof and fire-clay floor (section 4, fig. 18). At Mr. Field's over 3 feet of clean coal was seen, with a thin body of shale above, capped by a good sandstone. Mr. Field reports that some of the coal runs as high as 4 feet 4 inches, but that 3½ feet is a fair average. The position of this coal in the hills is such as to suggest the possibility of a large body of workable coal, the more so as it is believed that this coal may be the stratigraphic equivalent of that opened by Mr. Herbelan and Mrs. Tackett to the west of Deer Creek, which is known to be fairly persistent and of workable thickness. The position of this coal with reference to the railroad is favorable to its easy and cheap exploitation, and the slight westward rise of the beds in this vicinity should solve in large measure most of the difficulties encountered in the drainage of the mines.

The coal opened by R. T. Berry, southeast of Blaine and east of Hood Creek, may belong at this horizon. It measures 26 inches in

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thickness and is worked for local use. The coals along Irish Creek, near its mouth, are referred to the lower horizons in the Pottsville. They are reported workable in one or two places, but the writer was not able to verify this information. These lower coals are here and there partly cannel. The coal measured by G. H. Ashley near drainage level at Sarah is considered to be near the base of the Pottsville: it was reported 28 inches thick, with a 12-inch bench of cannel 8 inches from its top.

The coal mined along Brushy Creek is one of the most important of the lower beds. It has been referred to at times as No. 1 or the Barrett Creek coal, but its position with reference to the Sharon conglomerate outcropping along Brushy Creek in the vicinity of Cordell leads to another interpretation. Below Cordell at the bank of A. J. Soard this coal is 180 feet above the top of the Sharon, a much greater distance than appears about the town of Blaine, or along Deer or Barrett creeks. It is strongly probable, therefore, that the coal on Brushy Creek is higher than the Barrett Creek bed. It may

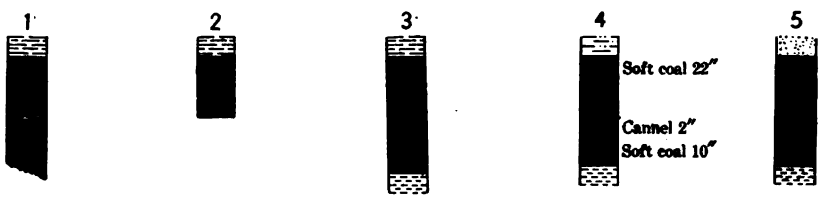

FIG. 19.—Sections of coal on Brushy Creek. 1, Two miles east of Blaine; 2, Simpson Steele, head of Brushy Creek; 3, Isaac Adams; 4, Garfield Moore; 5, near mouth of Big Branch. Scale, 1 inch = 5 feet.

correspond to No. 2 of the districts to the north, though without paleobotanic evidence such long-distance correlations have little value. Some of the coal along Brushy Creek contains a thin streak of cannel, as at the bank of Garfield Moore. It shows in general about 3 feet of coal, partly soft bituminous and partly splint. It appears to be persistent in the hills along Brushy Creek to the point where it disappears below drainage level about three-quarters of a mile above the mouth of Big Branch. It is an excellent coal for domestic purposes and furnishes all the inhabitants with fuel. The sections of this coal, measured by the writer, are given in fig. 19.

TECHNOLOGY OF THE COAL MINING.

Most of the mines in this quadrangle are small, none employing more than 75 men and very few averaging as high as 50 men daily throughout the year. The equipment is in most places comparatively simple. All the shipping mines are ventilated by means of furnaces, and drainage is usually natural, by means of ditches. In a few of the mines siphons are used for the drainage, and the occasional use

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of hand pumps is reported. None of the mines were reported to be gaseous. In the majority the coal is picked with the ordinary hand picks, but machine mining is practiced at the Torchlight mine, Sullivan compressed-air drills being used.

The width of the entries, the distances at which rooms are turned, and the size of pillars left vary considerably in the different mines. The main headings are run usually 8 or 9 feet wide, and the cross headings are a foot or two narrower. Rooms are turned every 33 feet or thereabouts and vary in width, but most are from 20 to 25 feet wide. The custom seems to be to run the rooms 200 or 250 feet long. The pillars left are from 8 to 13 feet wide.

All the coal is carried from the mines by mules in cars with capacities ranging from 1,200 pounds to 1 ton. Most of the mines have the larger-size cars, but one mine reports the use of a car with a capacity of 1,300 pounds. All the mines are drifts. Most have the ordinary cradle tipple, but that of the Torchlight Coal Company is more elaborate, employing a shaking screen. Most of the coal is shipped as run-of-mine, but it is sometimes screened to suit the buyer. When this is done a small loss, usually not more than 5 per cent, is entailed.

Nearly all of the coal mined in the quadrangle is shipped to places along the local railroad lines. Much of that mined at Rush and Winslow goes to Ashland, where it is used at the furnaces or for domestic purposes. That mined on Lost Creek by the Eastern Kentucky Railway is likewise used along the line or by the railroad itself. The cannel mined by the Kentucky Cannel Company at Boghead and Hunnewell is shipped abroad, where it is used as a gas enricher. Some of the coal mined at the Torchlight mine is shipped to the Pacific coast and other western points.

STATISTICS OF COAL.[a]

The following figures give an idea of the magnitude of the coal industry in this area during the last five years. The figures represent tons of 2,000 pounds each..

Coal production in Kenova quadrangle, 1902–1906.

County.	Loaded at mines.	Sold or used locally.	Total.	Value.	Average price per ton.
1902.	*Tons.*	*Tons.*	*Tons.*		
Boyd	241,127	870	241,997	$193,479	$0.80
Carter	268,056	13,345	281,401	285,271	1.01
Miscellaneous[b]	3,686	586	4,272	5,335	1.25
	512,869	14,801	527,670	484,085	
1903.					
Boyd	245,491		245,491	220,686	.90
Carter	256,321	8,905	265,226	289,130	1.09
Miscellaneous	22,713	1,550	24,263	26,819	1.11
	524,525	10,455	534,980	536,635	

[a] Statistics were obtained from the records of the United States Geological Survey.
[b] Miscellaneous, in each year, includes Lawrence County, Ohio, and Lawrence County, Ky.

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Coal production in Kenova quadrangle, 1902–1906—Continued.

County.	Loaded at mines.	Sold or used locally.	Total.	Value.	Average price per ton.
1904.	*Tons.*	*Tons.*	*Tons.*		
Boyd	69,067	28	69,095	58,304	.84
Carter	241,088	3,942	245,030	259,384	1.06
Miscellaneous	23,441	1,200	24,641	26,016	1.06
	373,596	5,170	338,766	343,704	
1905.					
Boyd	46,542	1,762	48,304	37,260	.77
Carter	138,135	7,084	145,169	144,448	1.00
Miscellaneous	10,310	100	10,410	9,750	.94
	194,987	8,896	203,883	191,458	
1906.					
Boyd	46,322	2,500	48,822	38,540	.79
Carter	154,482	4,266	158,748	144,899	.91
Miscellaneous	5,845	70	5,915	5,295	.90
	206,649	6,836	213,485	188,734	

Production at country banks only and for local trade.

County.	1905.			1906.		
	Tons of 2,000 pounds each.	Value.	Average price per ton.	Tons of 2,000 pounds each.	Value.	Average price per ton.
Boyd	516	$456		3,284	$3,931	
Carter	2,367	2,724		2,298	2,392	
Elliott	473	638		272	355	
Greenup	323	372				
Lawrence, Ky	7,621	8,658		2,612	2,348	
Lawrence, Ohio				2,020	2,525	
	11,300	12,848	$1.14	10,486	11,551	$1.10

According to the reports of the State inspector of mines of Kentucky, the production of cannel coal and of coke from 66 ovens in this area for the years 1901 to 1904 was as follows:

Production, in short tons, of cannel coal and of coke, 1901–1904.

	Cannel coal.		Coke.
1901	11,203	1901	23,320
1902	11,339	1902	23,075
1903	8,341	1903	22,323
1904	2,780	1904	17,980

CLAYS AND SHALES.

INTRODUCTION.

The clays of the Kenova quadrangle will be described by horizons, as some are scattered over the entire area, and the description by districts would involve needless repetition. All the clays of northeastern Kentucky have been deposited by the agency of water and are hence called sedimentary clays. They may be divided with regard to both their age and their adaptability into two classes—(1) clays which were deposited in Carboniferous time and are more or less closely associated with coal beds, and (2) recent clays, that is,

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those occurring in the present river and stream valleys. The former are by far the more important. For descriptive purposes the clays may be regarded as either plastic or nonplastic; the latter variety is also known as flint clay.

On pages 14–21 of this bulletin will be found a somewhat extended description of the beds in which these clays are found and the way in which they are classified according to their relative ages. The reader is referred to this preliminary description for explanation of many of the terms used in the following discussion. On page 29 also will be found a brief description of the clays, to which the general reader is referred. The following notes are intended for the use of those who are more particularly interested in the clay resources of this region, and hence the description will be given with considerable detail and will be accompanied by sections and analyses. The columnar section on the economic map will show the position of the more important clay horizons.

CLAYS IN THE CONEMAUGH FORMATION.

The clays highest geologically are in the Conemaugh formation. As a rule the plastic clays in this formation are the under clays of coal beds. The Conemaugh coal beds are irregular, both in distribution and in thickness, and the same is true of the associated beds of clay. Clay has been noted at a few horizons, but it is not worked at any place so far as known.

The shales in this formation are abundant and widespread. So far as known these have not been utilized, but it is certain that they are adapted to the manufacture of some types of building brick. They are present in the hills about Ohio and Big Sandy rivers and are conveniently situated with respect to transportation.

CLAYS IN THE ALLEGHENY FORMATION.

CLAY ASSOCIATED WITH VANPORT LIMESTONE.

The clay bed associated with the Vanport ("Hanging Rock") limestone easily outranks all the other clays in the Allegheny formation in distribution, quality, and quantity. This clay bed occurs near the base of the Allegheny; it usually lies from 10 to 40 feet above the top of the Homewood sandstone, or Pottsville formation, between coals Nos. 5 and 6. In the absence of coal No. 5 it may lie even nearer the Homewood sandstone.

Extent.—This clay bed is above drainage level at Coalgrove and Forestdale, Ohio, but the dip to the east soon carries it below drainage level. It has been opened and worked in the hills both east and west of Ashland and also north of Catlettsburg. The dip toward the center of the basin causes its disappearance near the mouth of Big Sandy River, and it does not reappear north of Louisa. From Louisa it occurs in the hills in a great arc, following the outer edge of

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the basin and coming back to Ohio River near Ashland. Its horizon is also above drainage level to the east and southeast of Cassville, W. Va.

This economic horizon, the beds at which contain clay, iron ore, and limestone, is indicated on the map (Pl. I) by a red line. It will be understood that the clay is not necessarily workable at all points on this line. The flint clay, which occurs in small amount associated with the plastic variety, will be found a great help in the field in locating these deposits, for, owing to its indestructible character, small fragments of the flint clay usually remain near the outcrops. Its position near the top of the massive Homewood sandstone should serve as an additional help in locating it.

Development.—The following firms work this clay: Petersburg Fire Brick and Tile Company, Coalgrove, Ohio; Ashland Fire Brick Company, W. T. Johnson, and O'Kelly Brick Company, Ashland, Ky.; Weaver Pottery Company, Catlettsburg, Ky.; Willard Fire Clay Company and Frailey & Rice, Willard, Ky. Besides the mines of the above firms, numerous small openings which had been worked in the past and many prospects were located by the writer during this investigation.

Physical character.—The clay at the horizon of the Vanport limestone is plastic, except for the small band of flint clay. The plastic clay is of two grades, the high (No. 1), and the low (No. 2). The flint clay is of slight economic importance owing to its thinness. The two following sections, one measured by G. H. Ashley 1 mile west of Ashland and the other by the writer at Willard, give an idea of the associated beds:

Section of clay bed 1 mile west of Ashland (Ashley).

	Ft.	in.
Sandstone, light brown	20+	
Coal	2+	
Shale, light drab	2	
Clay, light brown	6	
Clay, dark drab	1	6
Clay, drab, with scattered iron-ore concretions (Vanport limestone horizon)	2	
Shale, light drab, sandy	1	2
Shale, drab, ranging up to		8
Clay, dark drab to black, grading into light drab at middle	1	6
Clay, drab	3	
Flint clay		1–4
Clay, drab	3	6
Clay, dark drab, almost black		3
Clay, drab	8	

Four feet from the bottom of the lowest layer is about 1 foot of light-drab flint clay, similar to the best of the Pennsylvania flint clays.

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Section of clay bed at Willard, Carter County, Ky.

	Ft.	In.
Fire clay		4
Coal		4
Flint clay, bluish (reported)		4
Clay, dark, plastic	4	
Clay, light, plastic, harder than the above	2	
Vanport limestone:		
Iron ore, red (2 to 4 feet)	10	
Limestone (4 to 6 feet)		
Flint clay, thin band, formerly shipped to Olive Hill, Ky., and to Strasburg, Ohio.		

The Willard section differs from that at Ashland in having the workable clay above the limestone, and not both above and below, as in the section measured by Ashley and also in a section measured by the writer at the clay bank of William T. Johnson west of Ashland.

Section at the William T. Johnson clay mine, west of Ashland.

	Ft.	In.
Clay, dark	4	
Limestone ore (locally replaced by 4 feet of limestone), averaging		6
Bone, not always present		2
Clay, light drab	2	

The clay also occurs both above and below the limestone in the opening of the Petersburg Fire Brick and Tile Company at Coalgrove, Ohio, and the following section reported to the writer shows these conditions:

Reported section of clay bed at Coalgrove, Ohio.

	Ft.	In.
Clay, plastic	1	6–8
Clay, soft, plastic (No. 2)	5–6	
Limestone	4	
Clay (No. 1)	1	8

John Peters, president of the company, reports that the beds occupy these relative positions for several miles to the west. In the eastern part of Ashland, at the O'Kelly Brick Company's opening, the following section was measured:

Section of clay bed at the mine of the O'Kelly Brick Company, Ashland, Ky.

	Ft.	In.
Clay, upper, dark	4	6
Coal		4
Clay		3½
Coal		3
Clay	3	6

The siliceous clay given in the section (p. 117) at the base of the Allegheny formation near Louisa and Cassville probably belongs near this horizon. In the section measured at Cassville more than 6

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feet of clay is shown, and in the section on the Chesapeake and Ohio Railway about 1 mile north of Louisa about 8 feet of very similar material was measured.

In some places clay at this horizon is suitable for making pottery. A section measured by P. N. Moore at Amanda furnace, about 4 miles northwest of Ashland, shows a layer of pottery clay. This section is as follows:

Section of clay bed near Amanda furnace.

	Ft.	in.
Soil	4	
Clay shale	6	
Coal		4
Clay (No. 2)	3	
Clay, pottery	4	
Clay (No. 1)	3	
Limestone ore		8
Top of Vanport ("Hanging Rock") limestone.		

The product mined near Amanda furnace was shipped to Cincinnati. The only company in this quadrangle using clay from this bed in the manufacture of pottery is the Weaver Pottery Company, located near Catlettsburg. Of the 6 feet of clay measured in the company's bank only the upper 3½ feet is worked, the lower part of the bed being too sandy to give satisfaction. The presence of limestone pebbles has also caused the company some annoyance. When subjected to the baking process the carbon dioxide in the limestone is liberated, causing little particles of the vessel to flake off, and thereby either ruining the vessel or making it of second grade.

Chemical character.—The character and color of the clay in the different benches is, as a rule, fairly uniform. The fracture is rather irregular, and the clay is somewhat hard, but becomes soft on exposure and afterward makes better brick. The following analyses indicate the chemical character of this clay:

Analyses of clay associated with the Vanport ("Hanging Rock") limestone.

	1.	2.	3.
Silica (SiO_2)	60.54	40.14	56.40
Alumina (Al_2O_3)	25.89	43.72	28.00
Ferric oxide (Fe_2O_3)	1.75	1.98	
Manganese oxide (MnO)	.26		
Lime (CaO)	.53	1.60	1.30
Magnesia (MgO)	.12		
Potash (K_2O)	1.85		
Soda (Na_2O)	.65		
Water (H_2O)	2.06	12.56	14.30
Loss on ignition	7.43		
Sulphuric anhydride	.12		
	101.19	100.00	100.00

1. Willard, Carter County, Ky. Analysis made at the structural materials testing laboratory, United States Geological Survey, St. Louis, Mo. C. H. Stone, analyst.
2. Upper stratum of clay at Vanport limestone horizon, Ashland, Ky. Robert Peter, analyst.
3. Lower stratum of clay in No. 2.
Analyses 2 and 3 were kindly furnished by the Ashland Fire Brick Company.

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Applications.—As observed from the sections, most of the clay at this horizon is of No. 2 quality. It is used chiefly as a bond in the manufacture of fire brick and to a less extent for blast-furnace crucibles, boshes, coke-oven brick, etc. For the first-named purpose it is used by the brick companies at Ashland and Coalgrove. The product mined at Willard is shipped chiefly to Olive Hill, where it is mixed with flint clay to make a first-grade fire brick. The Willard fire brick is esteemed very highly by the clay men at Olive Hill. The Ashland Fire Brick Company has to import flint clay to make its high-grade refractory products. To make first-class refractory brick 67 to 80 per cent of flint clay is used, depending on the use to which the product is to be put, the remainder being plastic clay. For second-grade articles these proportions are reversed. It has been estimated that probably 500 to 700 pounds (according to the way the clay is used) will be sufficient to make 1,000 regulation 9-inch brick, when this clay is used alone as a binder. Its use in the manufacture of pottery has been referred to.

OTHER ALLEGHENY CLAYS.

Near North Kenova, Ohio, a clay was worked thirty years ago and hauled to Burlington and South Point, where it was used in making pottery. The old clay mines are now entirely fallen shut. The clay is 25 feet above No. 8 coal and directly below a massive sandstone, thus occupying a position near No. 9 coal. This correlation is strengthened by its distance of about 85 feet above the Sheridan coal. This is the only known occurrence in the area of a workable clay at this horizon.

At Cassville, W. Va., a flint clay has been prospected at a horizon lower than the above, in the hills north of the depot, by Frank Yates, of Louisa. It is found at an elevation of about 80 feet (barometric) above the tracks of the Norfolk and Western Railway, and about 100 feet below the base of the massive Mahoning sandstone near the top of the hill.

Section of Yates clay pit, Cassville, W. Va.

	Feet.
Cliff of brown, fine-grained, argillaceous sandstone.	
Shale, olive drab	5
Clay, drab, with numerous nodules of iron or lime, 2 to 4 inches in diameter, and distributed in lines	4½
Clay, drab, granular near crop, smooth farther back	1½
Clay, light drab, soft, plastic, smooth at back of pit, breaking with subflinty fracture, at crop apparently typical flint clay	2½
Clay, dark drab, hard, sandy	1
Clay, drab	3
Clay, brownish red	5

The same clay was also observed at a few points in the hills along Mill Creek and is reported 4 feet thick at one point. This flint-clay horizon is certainly worthy of very careful prospecting.

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Other clays locally workable undoubtedly exist in the Allegheny formation. Many shale beds also appear promising and will probably be used in the future for paving bricks, sewer pipes, and other purposes where inferior material may be utilized.

CLAYS IN THE POTTSVILLE FORMATION.

SCIOTOVILLE CLAY.

In the Pottsville formation, as in the Allegheny, one clay bed stands preeminently above the rest as regards quality, distribution, and thickness. This is the Sciotoville fire clay of the Ohio Geological Survey reports, less commonly known as the Logan clay. It has been extensively mined at Sciotoville and Portsmouth, Ohio. It occurs a few feet above the Maxville limestone, but this limestone and the beds immediately above it are very sparsely distributed in this quadrangle. On the map (Pl. I) the red line drawn on Everman Creek, Carter County, just at the western edge, and the red line on Tygarts Creek indicate the extent of this horizon above drainage in this area and also where it may be looked for. On Everman Creek, a short distance above the residence of David Childers, 4 to 6 feet of nonplastic clay shows and has been mined. A short distance below Mr. Childers's house the limestone outcrops in the road, apparently directly below the massive Sharon sandstone. The clay was not observed here. It was reported to G. H. Ashley as being 5 feet thick and resting directly against the limestone on North Fork of Oldtown Creek, and as usually being present without the limestone in the hills east of Tygarts Creek. West of Tygarts Creek the limestone is reported as generally present, but little seems to be known of the clay.[a] This horizon may be looked for along the western outcrop of the coal measures, occurring, as it does, at the base of this series of rocks. Where present it will usually be found a few feet above the Maxville limestone or, in the absence of this bed, occupying a similar position above the sandstones of the Waverly. Though its outcrop area in the Kenova quadrangle is extremely small, a few miles to the west its horizon is above drainage level in nearly the entire valley of Tygarts Creek. At Olive Hill, in Carter County, it is now extensively worked by the Portsmouth Harbison-Walker Company and the Olive Hill Fire Brick Company, and it shows the following section at one of the openings of the former firm:

Section of clay bed at Olive Hill, Carter County, Ky.

	Ft.	In.
Coal		2–6
Clay, No. 3	1–9	
Clay, drab flint (No. 1)	1–9	
Clay, "semihard" (No. 2)	1–5	

[a] These statements refer to the territory within the Kenova quadrangle.

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	Ft.	in.
"Pink eye"	3	
Shale, blue	1	6–8
Iron ore		4–8
Top of Maxville limestone.		

This order of superposition is usually maintained in this district. It will thus be seen that there may be four distinct varieties of clay present in this noted bed. Of these the nonplastic or drab flint clay is by far the most important and becomes the basis of refractory materials of the highest grade. The layer known as "semihard" is on a par with the clay at the horizon of the Vanport ("Hanging Rock") limestone, already described, though by some of the clay workers the Vanport limestone clay, at least at some points, is considered superior. The "semihard" is a plastic or No. 2 clay and is mixed with the flint clay in various proportions, depending on the desired quality of the product. No. 3 clay is also plastic, but of inferior quality to No. 2, while that called "pink eye" may be worked up into bricks, but the product is off color. The following analyses indicate the very high grade of the flint clay at this horizon, the percentages of silica and alumina approaching the theoretical values in kaolinite:

Analyses of Sciotoville flint clays of Kenova quadrangle.

	1.	2.	3.
Silica (SiO_2)	50.95	48.56	46.75
Alumina (Al_2O_3)	39.49	37.471	38.17
Iron oxide (Fe_2O_3)		Trace.	Trace.
Lime (CaO)		.112	.17
Magnesia (MgO)	.28	Trace.	Trace.
Phosphoric acid (P_2O_5)		.225	
Potash (K_2O)	.30	.289	Trace.
Soda (Na_2O)		.283	
Water (H_2O)	9.18	[a]13.030	14.03
	100.20	100.000	99.12

[a] Expelled at red heat.

1. Sciotoville fire clay. N. W. Lord, analyst; Ohio Geological Survey, vol. 7, 1893, p. 58.
2. Ridge between Grassy and Three Prong creeks, Carter County, Ky. Sample collected by P. N. Moore; Robert Peter, analyst: Report on eastern coal field: Kentucky Geol. Survey, vol. C, p. 10.
3. Near Olive Hill, Carter County. Analysis furnished by Ashland Fire Brick Company.

OTHER POTTSVILLE CLAY BEDS.

There are other clay beds below the Homewood sandstone, but they have not come into prominence. One of these is the clay associated with No. 4 coal, which lies under the Homewood sandstone. This coal and its underlying clay outcrop in the eastern part of Ashland, and the coal has been worked in a small way at many places on the road approaching the cemetery. In the summer of 1905 the O'Kelly Brick Company opened the coal and clay and began to utilize the clay at

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its brick plant in the eastern part of the city with satisfactory results. The following section was measured at the opening:

Section of coal and clay below the Homewood sandstone in the eastern part of Ashland, Ky.

	Ft.	In.
Sandstone, massive.		
Coal	1	6–7
Clay		10
Coal		8–9
Clay	2½–4	

The same bed of coal, with its underlying clay and clay parting, also occurs on Catletts Creek, and there is no reason why this clay should not be exploited in connection with the coal here, unless it be its relatively great distance from transportation.

In the hills about the head of Johns and Field branches, Carter County, a few prospect holes have been made on a bed of clay lying a few feet below the Homewood sandstone. This position is similar to that of the clay occurring in the eastern part of Ashland and on Catletts Creek. On the land of Judge John W. Barber 4 feet of sandy clay was measured at a prospect which had not penetrated the bed far enough to reveal its real character and thickness. This bed should be further prospected in these hills.

RECENT CLAYS.

The recent clays are found in the flood plains of the rivers and small streams and are very common, many small streams having flood-plain deposits which extend well up to their heads. These flood-plain clays are very erratic in their distribution in the valleys of the larger streams, and there is no means of pointing out where they are most likely to occur. They range in thickness from 1 foot to over 4 feet. Often in working a clay bed a sandy clay is encountered, which makes "dead" brick. These streaks of sand are also utilized by the brick manufacturers, but for certain purposes this sand has been found unsuitable owing to the intermixture of particles of coal. The deposits worked at present are confined to the valley of Ohio River in the vicinity of Ashland, where there is a local market, cheap coal, and transportation facilities. The flood-plain clay is used chiefly for ordinary red building brick, though it is adapted to the making of tile, shingles, fireproofing, etc. It is made into brick at the Means-Russell plant, west of Ashland, and by the J. J. Gates Company and the O'Kelly Brick Company in the eastern part of the city. The smaller flood plains contain clays which perhaps will not compare in quality with those of the larger river valleys, but which may be worked up into material suitable for local country use. F. R. Bussey has utilized such material from the flood plain of Harriet Branch of Little Blaine Creek. The deposit is here only 4 feet thick, but it illustrates the possibilities existing on all the smaller creeks. Flood-plain

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deposits along Big Sandy and Little Sandy have not even been prospected. Undoubtedly valuable deposits of clay exist along both these streams, and they may be utilized later for common and pressed brick, tile, paving brick, sewer pipe, etc. Experiments having in view the adaptability of these flood-plain clays to the various purposes enumerated above should certainly be carried out.

TECHNOLOGY AND STATISTICS.

All the clay mines in this area are drift mines, in which the workings are very irregular. The mines are drained either naturally or by siphon and pump, and ventilation is either natural or by furnace. In mining the clay the upper part of the bed is usually shot out by powder or dynamite and the lower part pried up. The clay is hauled from the mine in ordinary mine cars drawn by mules. The following table will give an idea of the magnitude of the clay industry in this region during the last five years:

Statistics of clay products in the Kenova quadrangle, 1902–1906.

Year.	Quantity of brick, including fire, vitrified, and common building brick.	Total value.[a]
	Thousands.	
1902	10,587	$133,633
1903	12,736	179,221
1904	14,861	92,354
1905	11,574	128,400
1906	12,826	152,631
	62,584	686,239

[a] These figures include values of pottery also. The figures were obtained from the files of the United States Geological Survey.

The seeming discrepancies in the above figures are due to variations in the amounts of fire brick and ordinary red building brick produced. For instance, the figures indicate a very unusual production of the more valuable fire brick in 1903, followed by a falling off in this commodity and an increase in the production of the less valuable ordinary red building brick in 1904.

It has been found inexpedient to separate the statistics of the fire brick and other varieties, owing to the small number of manufacturers of fire brick during some of the years. For the same reason it has been thought inadvisable to tabulate the statistics of the production of raw clay. The United States Geological Survey has figures for this product for only 1905 and 1906, and the industry is yet in its infancy. It is probable that it may never grow to great proportions, as most of the clay will continue to be worked up near the mines to satisfy home consumption. During 1905 and 1906, 20,168 tons of

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clay, of 2,000 pounds each, valued at $11,855, were shipped from the clay mines. All this has come from the clay at the horizon of the Vanport ("Hanging Rock") limestone.

MARKET.

The market for the clay products of this area is rather local. Most of the red building brick is used at home or shipped to the neighboring towns in West Virginia and eastern Kentucky. The fire brick is either used locally at the furnaces in Ashland or shipped up or down Ohio River, along which there is considerable demand for such material.

LIMESTONES AND IRON ORES.

INTRODUCTION.

The iron ores of the Hanging Rock region of Kentucky were of great importance in the seventies and eighties, but owing to the introduction of cheaper ores from Alabama and the Lake Superior country, and to the gradual disappearance of the forests on which the charcoal furnaces depended, the iron industry of this region has declined, and at present no furnaces depending on the local ore supply are in operation. (See Pl. V.) The ore diggings are now fallen in, and in many places have entirely disappeared, so that it is not easy to trace them. The following descriptions are therefore necessarily brief, especially those relating to the block and kidney ores, which at present are not worked at all. For fuller descriptions of the iron ores as a whole the reader is referred to P. N. Moore's report in vol. C of the Kentucky Geological Survey, from which the writer has freely drawn.

Where the iron ores are better known than their associated limestone beds the description of the limestones is made subsidiary.

IRON ORES.

GENERAL OUTLINE.

The iron ores of this region are chiefly earthy carbonates, spathic ores, or siderites, but on the outcrop and at variable distances in, depending largely on the porous or nonporous character of the roof, the ores have been altered to the hydrous ferric oxide, limonite. The ores may be classified as follows: (1) Limestone ores, (2) block ores, (3) kidney ores, (4) black band ores.

Limestone ores are those which occur upon or very near the top of a limestone stratum. In many localities they occupy a broader field than the limestone, but the term is still applied if the ore occurs

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A. ABANDONED PRINCESS FURNACE.

B. ABANDONED BELLEFONT FURNACE, SHOWING RUINED HEAD WORKS.

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near the stratigraphic position of the limestone. In eastern Kentucky these ores occur at two horizons—the lower associated with the Maxville and the higher with the Vanport limestone. Owing to their purity, uniformity, richness in iron, and ease in working they have been among the most highly valued of all the iron ores in this region.

Block ore and kidney ore are so called from their physical appearance. The former cleaves into more or less square or rectangular prisms when raised from its bed; the latter derives its name from its peculiar kidney shapes. Both varieties occur as unaltered carbonates or siderites, except where oxidized to limonites on or near the outcrop. The term "black band" is applied to beds of carbonate of iron with more or less bituminous and earthy matter associated.

Geologically these ores occur throughout the Carboniferous rocks in the Kenova quadrangle, but the most important are found in the two lower formations, the Allegheny and the Pottsville. These iron ores are all bedded deposits in the sense that they occur at fairly well-defined geologic levels, which are persistent over broad areas. The skeleton section (fig. 20) shows their relative position.

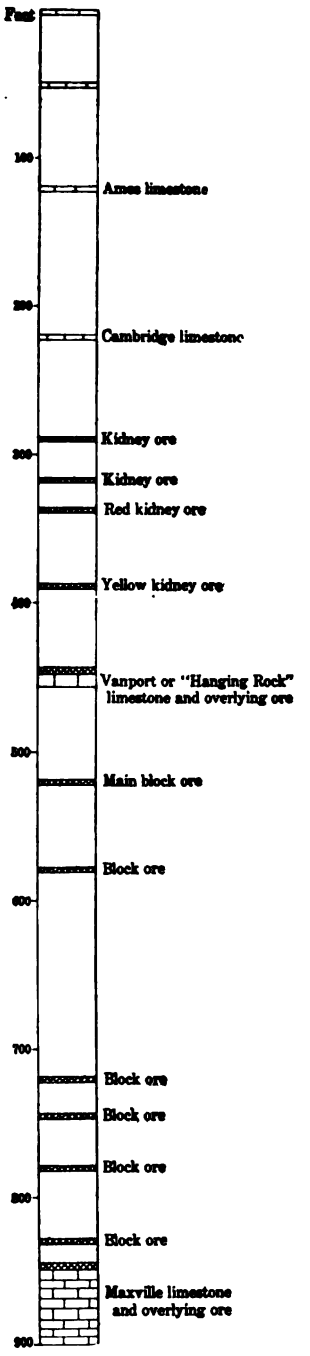

FIG. 20.—Skeleton section showing relative position of limestone and iron ores.

LIMESTONE ORES.

VANPORT LIMESTONE ORE.

Geologic position.—The higher of the important limestone ores is that associated with the Vanport ("Hanging Rock") limestone and hence known as the Vanport limestone ore. It is often known also as the red limestone ore and in the Kentucky Geological Survey reports as the "Ferriferous" limestone ore. It occurs from 10 to 40 feet above

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the top of the Pottsville, between coals Nos. 5 and 6, the latter being known about Ashland as the "limestone coal" on account of this fact.

Extent.—The Vanport ore horizon is found in both Ohio and Kentucky. In Ohio its outcrop area is small in this quadrangle, but it is very extensive to the north and west. As it lies so near the top of the Pottsville, structure contours drawn on the latter hypothetical plane apply equally well for this ore horizon and for its associated limestone and plastic clay. Moreover, the red line drawn on Pl. I to represent the outcrop of the clay represents equally well the iron ore and limestone. Immediately south of Ohio River its western limit is beyond the border of this quadrangle and is reported by Moore as being about a mile below Amanda furnace, a few miles northwest of Ashland. The main western outcrop in the Kenova quadrangle appears at its northern edge in the hills between Little Sandy River and East Fork and continues southwestward to the point where the boundaries of Elliott, Lawrence, and Carter counties come together. From this point the general trend of the outcrop is southeastward beyond Big Sandy River. In Boyd, Greenup, and Carter counties much of the ore at this horizon has been removed along the outcrop, but good ore was seen in Lawrence County near the town of Blaine and in the hills between Adams and Prosperity.

Character.—Though the red line indicating the position of the Vanport limestone and its associated clay and iron ore has been drawn continuously on the economic map, this by no means indicates that the ore and limestone will be found continuously. On the contrary, it is known that the limestone and the accompanying ore are in many places not present, and where present are locally variable in thickness. The ore rests on the top of the limestone, and the bounding surface between ore and limestone, according to Moore, is very irregular, being full of little ridges and depressions. The limestone ranges up to 8 feet in thickness, but may be absent where the ore is present. The ore itself ranges from a few inches to a few feet in thickness, but may be pockety and the pockets may be several feet thick. The section of fire clay at Willard, Carter County, and at William T. Johnson's clay mine, west of Ashland, and Moore's section at Amanda furnace illustrate the thickness and associations of the ore and limestone.

The limonite ore occurring at the outcrop is usually brown or red, more commonly the latter, and in general dense and close grained. The red ore is the more valuable. The carbonate or unaltered ore is dense, close grained, and bluish or grayish in color, and therefore is known as the blue limestone or the gray limestone ore. Most of the furnaces used the limonite ore, as the furnace men were unable to produce a coarse-grained foundry iron from the carbonates. The

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following analyses illustrate the character of both the limonitic and the sideritic phases of the limestone ore:

Analyses of limestone ores of Kenova quadrangle.

	1.	2.	3.	4.	5.	6.	7.
Ferric oxide (Fe_2O_3)	57.551	51.802	71.680	60.206	None.	65.395	31.544
Iron carbonate ($FeCO_3$)		10.594			62.002	None.	30.708
Alumina (Al_2O_3)	6.017	4.523	4.155	1.044	2.900	3.484	1.779
Manganese oxide (MnO)	[a].130		.090	Trace.	Not est.	Not est.	
Manganese carbonate ($MnCO_3$)		Trace.			.553		.060
Calcium carbonate ($CaCO_3$)	.150	7.480	.880	.285	6.880	8.580	2.730
Magnesium carbonate ($MgCO_3$)	.758	.440	.050	.381	2.243	[b]1.998	.141
Phosphoric anhydride (P_2O_5)	.057	.570	.084	.161	.149	.441	.421
Sulphuric anhydride (SO_3)	.105	.089	.270	.852	.302	.336	.491
Silica (SiO_2) and insoluble silicates	25.450	15.730	12.650	25.930	22.660	10.480	25.430
Combined water (H_2O)	10.300	8.772	10.800	[c]11.141		9.346	6.523
	100.518	100.000	100.159	100.000	97.689	100.000	100.000
Metallic iron (Fe)	40.285	41.357	50.176	42.144	29.982	45.776	36.627

[a] Brown oxide of manganese. [b] Magnesia. [c] And loss.

1. So-called slate ore, occupying the place of the limestone ore, from ridge between Cane Creek and Wilson Creek. Hunnewell furnace. Kentucky Geol. Survey, vol. A, pt. 1, p. 114. Robert Peter and J. H. Talbutt, analysts.
2. Limestone ore from Hoods Creek near Bellefont furnace. Idem, p. 20.
3. Limestone ore from the Graham bank, near Willard, Carter County. Average sample from the stock pile. Idem, p. 55.
4. Limestone ore from Brush Creek, Pennsylvania furnace. Idem, p. 114.
5. Gray limestone ore, from J. P. Jones's drift near Ashland. Selected from the interior of the bank. Idem, p. 37.
6. Same as No. 5, but from exterior portion of the bank. Analyses 5 and 6 show well the changes which occur when the original ore is exposed to the atmosphere and surface waters.
7. Gray limestone ore from Mount Savage furnace, Carter County. Idem, p. 51.
Analyses 1 to 4 and 6 represent limonites; 5 and 7 carbonates.

The analyses given above will also be found in P. N. Moore's report on the iron ores of Boyd, Greenup, and Carter counties.[a] The samples were collected by Mr. Moore.

The following table shows more concisely the amounts of metallic iron, sulphur, and phosphorus in both varieties of ore at the principal limestone ore horizons:

Average iron, sulphur, and phosphorus content in limestone ores.

Name of ore.	Constituent.	Limonites.		Siderites.	
		Per cent.	Analyses averaged.	Per cent.	Analyses averaged.
Vanport ("Hanging Rock") limestone ore	Metallic iron	43.49	4	30.61	2
	Sulphur	.132	4	.15	2
	Phosphorus	.090	4	.174	2
Maxville limestone ore	Metallic iron	47.79	7	35.05	4
	Sulphur	.089	2	.81	3
	Phosphorus	.147	7	.20	4

The amounts of ferric oxide and iron carbonate in the analyses at the top of this page show the fundamental difference between the oxidized and unoxidized ores. The amount of metallic iron in the

[a] Kentucky Geol. Survey, vol. C, 1884, pp. 90, 92.

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limonites ranges in general from 40 to 50 per cent, rarely going above or below these limits. In the unaltered ores the metallic content is much lower, ranging from 25 to 40 per cent. The remaining constituents are variable, but silica and insoluble silicates are high. Sulphur is low, except in analysis No. 4; phosphorus is in general high. The last table also indicates these facts.

MAXVILLE LIMESTONE ORE.

Geologic position.—The lower of the important limestone ores rests directly upon the Maxville limestone, as shown by the section obtained at Olive Hill, Carter County (pp. 118–119).

Extent.—The limestone itself is above drainage level in the valleys of Everman Creek, North Fork of Oldtown Creek, and Tygarts Creek, in the northwest corner of the quadrangle. It is of very scant extent in this area, but to the west and nothwest its outcrop is generally above drainage level. The red line on the map (Pl. I), representing the fire clay lying above the limestone, may be taken also to represent the top of the Maxville limestone and its overlying ore, where the latter is present.

Character.—Where exposed on Everman Creek the limestone is from 20 to 25 feet thick. West of the area it is much thicker, locally reaching 100 feet and more, but in some places it is entirely wanting. Many of the deeper wells drilled for oil and gas have penetrated this limestone and proved it to be very thick and generally persistent over all this area. Sections of these deep wells are given on Pl. VI. The limestone is the usual bright-gray variety, and has been burned and used for fertilizer, for which purpose there seems to be an ample supply. It is not improbable that it may also prove suitable for the manufacture of Portland cement.

The iron ore overlying this limestone is erratic in occurrence and thickness, and in these respects is like the ore associated with the Vanport ("Hanging Rock") limestone. In quality it is comparable with that ore, and its content of metallic iron in its altered and unaltered phases is similar to that of the higher ore. It is apt to be more siliceous than the Vanport ore and in many places contains too much sulphur. On the whole it has proved to be one of the most valuable ores in this part of Kentucky.

ORIGIN OF LIMESTONE ORES.

An extended description of the origin of the limestone ores is hardly appropriate in this bulletin. For those interested in the theoretical side of the subject Moore's description[a] will be found most interesting and suggestive. As a result of studies made by the writer

[a] Kentucky Geol. Survey, vol. C, 1884, pp. 83–88, 94.

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in the course of mapping this region in the summer of 1905, certain conclusions were reached which are summarized in an article in Economic Geology.[a]

BLOCK ORES.

Geologic position.—Most of the block ores are found in the Pottsville formation and in the lower part of the Allegheny formation. They have been separated by Moore into two groups with reference to their stratigraphic position—the upper block ores and the lower block ores. The former occupy the interval from 90 feet below the Vanport limestone to about 50 feet above it, and the lower block ores are confined to the lower 125 feet of the Pottsville. The skeleton section (fig. 20, p. 123) shows their relative positions.

Extent.—The area in which the block ores occur is along the western and southern edges of the quadrangle, chiefly west and south of the line of outcrop of the Vanport limestone. The lower block ores are mostly confined to the territory west of Little Sandy River, but the area occupied by them in this section of the quadrangle is a small part of their extent in this portion of the State. The upper block ores are more widely distributed in this particular area, their boundary extending to the east beyond that of the lower block ores and the Vanport limestone.

Character.—Like the limestone ores, the block ores occur both in the oxidized condition and as unaltered carbonates. They are characterized by being more persistent than the limestone ores and by more uniform thickness in individual beds, but they vary greatly in thickness and quality among themselves. Their most common impurity is sand. They are leaner ores, as a rule, than the limestone ores, and the lower block ores are inferior to the higher block ores. Their richness in iron apparently bears an inverse relation to their thickness, for it has been commonly observed that the leanest ores are the thickest, and vice versa. The following table shows their content in metallic iron, sulphur, and phosphorus:

Average iron, sulphur, and phosphorus content in block ores.

Kind of ore.	Constituent.	Limonites.		Siderites.	
		Per cent.	Analyses averaged.	Per cent.	Analyses averaged.
Upper block ores	Metallic iron	43.85	12	34.42	4
	Sulphur	.204	10	.444	4
	Phosphorus	.161	10	.229	4
Lower block ores	Metallic iron	33.48	10	29.74	4
	Sulphur	.137	9	.088	4
	Phosphorus	.238	9	.159	4

[a] Phalen, W. C., Origin and occurrence of certain iron ores of northeastern Kentucky: Economic Geology, vol. 1, No. 7, 1906, pp. 660–669.

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KIDNEY ORES.

Geologic position.—Most of the kidney ores which have proved of value have been found in the lower part of the Allegheny formation. The more important range from about 40 or 60 feet to 100 feet above the Vanport limestone. In this interval there are from three to six beds of kidney ore of local importance. The lower of the more important ores has been called the yellow kidney ore. It lies about midway between the Winslow coal and the Coalton coal. Since most of the oxidized kidney ore has a yellow color, due to limonite, this name is not distinctive, but it has been commonly applied to the ore at this particular horizon. About 50 feet above the yellow kidney ore and 25 to 30 feet above the Coalton coal is another horizon of fairly persistent kidney ore called the red kidney ore, from the prevailing color of the weathered material. Other kidney ores occur in the Allegheny formation above the red kidney, but they are not so important as the two just mentioned.

Extent.—The western and southern boundaries of the kidney ores coincide roughly with the line representing the outcrop of the Vanport limestone and clay. Beyond this boundary, to the south and west, these ores are of minor importance. Within the arc formed by the outcropping Vanport limestone and clay these ores will be found in a zone of a mile or more in width. They occur in the hills along Ohio River and generally over the northern part of Boyd County, where they have been extensively benched. They are found in Carter County near Willard and also in the region between Little Sandy River and East Fork. In Lawrence County, as a rule, they have been very little explored.

Character.—The name of these ores is very suggestive of their physical appearance. Though occurring at perfectly distinct geologic levels, they do not form continuous beds or layers of ore, but are scattered through zones from 3 to 6 feet thick. Like the limestone and block ores they are found in all stages of transition from the pure carbonate ore, unaltered by atmospheric influences, to practically pure limonite on the outcrop. Their origin seems to be fairly obvious. It is quite probable that they have originated in much the same way as limestone and other concretions—that is, by the gradual accretion of ferrous carbonate from the surrounding beds. This segregation has probably been chiefly lateral, for otherwise the definiteness of geologic level, which is so common, would hardly persist, and the kidneys would be scattered throughout the shale and sandstones. The fact that the nodules coalesce into peculiar shapes strongly suggests such origin. Furthermore, the beds whence the nodules must have derived their ferruginous matter must have been rich in iron. These beds thus represent a period of deposition of

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highly ferruginous sediments. Analyses of five samples of oxidized kidney ore collected in this region give the following averages: Metallic iron, 43.372; sulphur, 0.049; phosphorus, 0.166. These figures show that these ores are comparable with the limonite phases of the limestone and block ores.

BLACK-BAND ORES.

The term black-band ores is applied to beds of carbonate of iron with more or less bituminous and earthy matter associated. A notable occurrence of this ore is on the property of the Torchlight Coal Company on Levisa Fork, in Lawrence County. The deposit lies about 15 feet below coal No. 4 and is from 8 to 12 feet thick, consisting of layers of black or carbonaceous siderite, from 1 inch to 3 inches thick, alternating with thin layers of bituminous shale. The ore, which carries 55.12 per cent of iron carbonate, compares favorably with the Scotch black-band ores. An analysis of the ore from this locality follows, together with analyses of a similar ore from Perry County, Ohio, and of one from Scotland. These were kindly furnished by Col. Jay H. Northup, of Louisa.

Analyses of black-band ores.

	Threemile Creek, Kentucky.	Perry County, Ohio.	Scotch black band.
Iron carbonate ($FeCO_3$)	55.12		
Ferrous oxide (FeO)		43.37	
Ferric oxide (Fe_2O_3)	9.12	4.10	36.59
Manganese oxide (MnO)	2.90	1.50	2.70
Alumina (Al_2O_3)	3.26	6.05	.29
Lime (CaO)	6.12	3.00	3.24
Magnesia (MgO)	1.92	.25	1.92
Carbon dioxide (CO_2)		30.50	19.09
Phosphoric acid (P_2O_5)	Trace.	Trace.	
Sulphide of iron (FeS_2)	.78	1.56	1.63
Water (H_2O)		.58	.84
Organic matter	10.25	6.25	18.02
Insoluble residue	9.18	2.80	9.91
	98.65	99.96	94.23
Metallic iron	36.96	36.49	25.63

SUMMARY.

The ores of this part of Kentucky practically ceased to count as sources of iron some time ago. In spite of this fact it has been thought advisable to give a brief outline of their geology and occurrence. Though they have little value at present, they may be more important in the future. When the various ore beds were worked, the oxidized material at or near the outcrop was sought for, as the furnace managers were professedly unable to work the blue or gray carbonate and produce the desired coarse-grained foundry iron. The oxidized ore was obtained by benching or stripping, a process which,

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though economical for ore occurring at the outcrop, could not be carried into the hills for any distance, and thus but an insignificant percentage of the ore bodies has been removed from the hills. The remaining ore is largely iron carbonate. It is very likely that when the cheaper ores now on the market become scarce and prices advance the higher grades of these ores will be worked. To reach satisfactory results the mining methods employed must be studied most carefully, but the fact that similar thin beds of iron ore have been successfully worked in Europe is significant.

LIMESTONES.

Brief descriptions have been given of two limestones, the Vanport ("Hanging Rock") limestone near the base of the Allegheny formation and the Maxville limestone underlying the Pottsville. The Conemaugh contains higher beds of limestone, a few of which are persistent and are hence of value in unraveling the stratigraphy. Some of these beds are also of local economic importance.

The lowest limestone in the Conemaugh is the most persistent of all. It usually lies very near the top of the Mahoning sandstone, or, rather, the group of sandstone lying at the base of the Conemaugh formation. It is very widespread, but not everywhere a typical limestone in its development. Along Big Sandy River it may be traced rather continuously from the mouth of Dock Creek to Roundbottom. At some points along this stretch it is a calcareous sandstone 4 to 5 feet thick, containing abundant crinoid stems and other fossils. About one-eighth of a mile below Lockwood on the Kentucky side it has much the same character, but here it is weathered and dark in appearance and crumbles easily under the hammer. In the hills back of Cassville it is a fossiliferous shale and is closely underlain by a thin bed of coal, called the Mason coal by I. C. White,[a] and probably correlating closely with the Brush Creek coal of western Pennsylvania. Throughout the southern part of Boyd County it is very persistent, but much of it is too sandy to burn for fertilizer. In the hills east and west of Willard and on most of the streams flowing into Little Fork from the east it is 4 to 5 feet thick. In this region it is siliceous and does not react with acid on the weathered surface, but on being broken it is found to contain much lime. At Willard it occurs 180 feet above the Coalton coal and about 230 feet above the Vanport limestone. When burned this limestone will probably yield a fairly satisfactory fertilizer. This limestone is probably the representative of one of the Cambridge limestones of the Ohio Geological Survey. The horizon is in many places char-

[a] West Virginia Geol. Survey, vol. 2, 1903, p. 280.

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acterized by two calcareous beds lying a small distance from one another, as indicated in the following section:

Section of Cambridge limestone 1 mile west of Potomac on Whites Creek.

Concealed.	Ft.	In.
Sandstone, fossiliferous	4	
Shale	14	
Limestone, crinoidal		6
Shale, blue	1	

A short distance away, near the residence of J. L. Bowling, the following section was measured:

Section of limestone near residence of J. L. Bowling, west of Potomac, Ky.

	Feet.
Sandstone, massive	30
Concealed	15
Sandstone, laminated	2
Concealed	23
Sandstone, fossiliferous	4
Shale	23
Limestone	1
Shale	5

The fossiliferous sandstone and the limestone lying from 14 to 23 feet below may represent the upper and lower Cambridge limestones of Ohio.

About 80 to 100 feet above the Cambridge limestone is another limestone, also largely siliceous, which probably corresponds to the Ames of the Ohio and Pennsylvania surveys. It is seen at many places on the headwaters of East Fork of Little Sandy and is rather persistent in the hills east and southeast of Cassville, W. Va. In the latter region much of it is characterized by calcareous pebbles on its outcrop. This limestone is possibly valuable for fertilizer and may repay careful prospecting. Other limestones have been observed higher in the Conemaugh at 70 and 120 feet above the Ames. These higher Conemaugh limestones are generally characterized on their outcrops by the presence of a few limestone pebbles. Like the lower limestones, they may prove locally valuable.

BUILDING STONE.

The only rock suitable for building stone in this area is sandstone, and of this there is a great abundance. As a rule this rock will not bear the cost of transportation, but as a local building stone it has proved of value in the construction of culverts for the railroads which pass through the area and also in the construction of chimneys, fireplaces, etc., all through the country. Some of this sandstone has also been used in the construction of dwellings. Very little of it, if

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any, can be cut into blocks of any considerable dimensions, but for rougher purposes it serves as a cheap and very accessible source of supply.

Most of the sandstone in this area is micaceous, much is feldspathic, and as a rule it contains iron oxide. It ranges from very fine-grained to conglomeratic, in which few of the quartz pebbles exceed an inch in their largest dimension. A large amount of this sandstone is friable, disintegrating readily to fine sand. Such rock was used in the construction of a residence and of a building in Ashland, and so far as known proved satisfactory. It would appear, therefore, that freshly cut blocks, even of this friable sandstone, season fairly well and become resistant.

In the Conemaugh formation the most important sandstone lies at its base and is known as the Mahoning sandstone. This sandstone is well exposed along Big Sandy River near its mouth, in both Kentucky and West Virginia. Near Kenova it appears to be thick bedded enough to supply dimension stone. At this point, besides being very massive, it is very coarse grained and locally conglomeratic. It has been used by the Norfolk and Western Railway in this locality. To the south, up Big Sandy River, it is above drainage level nearly to the mouth of Dock Creek in West Virginia and to Savage in Kentucky. In building the Norfolk and Western Railway and in the recent changes in grading the Chesapeake and Ohio Railway much of this rock has been used. A higher sandstone in the Conemaugh formation has been quarried for local purposes on Whites Creek, near Egypt. The Conemaugh also contains other sandstone beds which, though suitable for local purposes, are not sufficiently valuable to export.

Sandstone from the Allegheny formation has been used along Ohio River opposite Ashland. At this point the sandstone above the Coalton coal thickens abnormally and has been quarried by the Norfolk and Western Railway for use along its line. It has furnished much rock of fair dimensions.

The Pottsville formation contains many sandstones of considerable thickness, much of which has been used in the construction of the Norfolk and Western Railway along Tug Fork, and by the Chesapeake and Ohio Railway on Levisa Fork. The Homewood or upper sandstone member of this formation outcrops near Ashland and occurs as a very massive cliff between the eastern limits of the city and Cliffside Park. The rock has been used with very satisfactory results in the construction of dwellings. Lower sandstones of the Pottsville have proved locally valuable.

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GLASS SAND.

Some of the sandstones in this quadrangle may be of sufficient purity to furnish raw material for making glass, but most of them appear to be too ferruginous for such a purpose. Some of the sand found in the flood-plain deposits may, when washed, also prove suitable. A deposit of the latter type was reported on the property of Samuel Ferguson, at North Kenova, Ohio. The Mahoning sandstone and the Homewood and other sandstones in the Pottsville appear to be of sufficient purity in places for glass making, but no definite statement can be made as to the suitability of this material at any particular point. The Mahoning near Willard and the Homewood near Mount Savage may repay careful prospecting for glass sand. Before pronouncing on the fitness of sandstone or loose sand for glass making it should be examined microscopically and chemical tests should be made to determine the amount of iron, which, if present in too large quantities, renders the glass opaque. Large amounts of aluminum and magnesia also have a deleterious effect. Better than either of these tests is a practical test of the material. It should be remembered also that some sandstones, though naturally too rich in iron for glass making, yield after crushing and washing a suitable raw product.

SALT.

Many years ago salt was obtained from wells sunk on Big Sandy River near Zelda. The old salt works have long since disappeared. South of Zelda, near Catalpa, some of the wells drilled for oil and gas have struck salt water, which is still running.

METALLIC ELEMENTS.

Numerous reports reached the writer, while working in the Kenova quadrangle, regarding discoveries of lead and other metals. Concretions containing small amounts of lead and zinc sulphides have been seen. It may be safely stated, however, that in this area the metallic elements, such as gold, silver, copper, lead, etc., occur in such small quantities that time and money spent in exploration for them will meet with but little return.

DIAMONDS.

Diamonds have been reported as having been found in Elliott County, in the peridotite described on page 21. The name of kimberlite has been applied to this rock owing to its resemblance to the diamondiferous rock of South Africa. The writer can not substantiate these reports. The peridotite is, however, characterized by the presence of numerous garnets of small size. None of gem quality,

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so far as known, have ever been obtained, but it is by no means certain that they do not exist. The extent of the outcrops of peridotite is indicated on the economic map (Pl. I).

OIL AND GAS.

SUBSURFACE STRATIGRAPHY.

INTRODUCTORY STATEMENT.

In the pages dealing with the general stratigraphy of the various districts into which the quadrangle has been divided, brief descriptions have been given of the character of the rocks appearing at the surface. A knowledge of rocks lower than these has been obtained from the deep wells drilled in search of oil and gas. Some of the facts so obtained are merely supplementary to those already known, but much of the information is entirely new. It will be understood that the way in which our knowledge of these underlying rocks is obtained presupposes many factors which are liable to lead to error in attempting close correlations. First, a division of these lower rocks into well-recognized geologic units is based almost solely on variations in physical character, a standard which often fails entirely when applied to surface rocks. Second, the determination of lithologic distinctions is often left to persons incompetent to make such distinctions. Third, if measurements are not made with the steel tape other errors are likely to creep in. On the other hand, horizons at which, from a general knowledge of the underground stratigraphy of a given district, oil and gas are considered liable to occur are usually expected by the driller, and hence the position of their tops and bases is generally detected within very close limits.

CARBONIFEROUS SYSTEM.

PENNSYLVANIAN SERIES.

The base of the Pennsylvanian series, resting on the top of the Maxville limestone, has been chosen as a datum plane in arranging the deep-well records (Pl. VI). The Maxville limestone is present in all the sections except one shown by a well (No. 9, Pl. VI) drilled near the mouth of Blaine Creek, and serves as a convenient guide from which to reckon. The complete absence of this limestone in the Blaine Creek record is not easily explained, since the Horseford Creek well (No. 10), a mile and a half away, shows the limestone 140 feet thick. The limestone is probably present in the Blaine Creek well, but was called sandstone.

The well showing the greatest thickness of Pennsylvanian or coal-bearing rocks is the Horseford Creek well (No. 10), in which more than 1,000 feet of these rocks is represented. The explanation is that the well was started in Conemaugh rocks well up in this series. The

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prevailingly sandy character of the lower part of the Pennsylvanian rocks is apparent. The line which has been drawn at the top of the lower sandstones of this series is not the top of the Pottsville, since from surface observations it is known that the Pottsville must be thicker than the intervals included between this line and the top of the Maxville limestone, as in the Shope Creek well, Summit well, Catletts Creek well, and others. This lower group of sandstones contains salt water and gas, and this fact has helped to determine the position of the correlation line at its top. It is probable that in several of the sections this lower group of sandstones may correspond to the Sharon conglomerate, which is known to consist of two members, as on Everman Creek, Carter County. The well showing the greatest thickness of Pottsville rocks is the Griffith Creek well (No. 19), which starts in rocks of this formation and reaches the Maxville limestone at a depth of 775 feet. In the southeastern part of the area, therefore, the Pottsville rocks are very nearly 1,400 feet thick, as compared with a thickness of 350 to 400 feet in the northwestern and western parts. The first figure, 1,400, added to the average thickness of Allegheny, Conemaugh, and higher rocks, makes the Pennsylvanian series in the Kenova quadrangle, in round numbers, about 2,000 feet thick. In certain sections the highest limestone plotted has not been regarded as the Maxville. In doing this each case had to be considered on its own merits in connection with the known surface geology of the immediate locality. At some points where limestone is shown on the surface on the plotted record, it is probable that sandstone has been designated as a limestone or lime by the driller.

MISSISSIPPIAN SERIES.

The Mississippian series includes the rocks from the top of the Maxville limestone to the base of the Bedford shale; no record shows the presence of red shale above the top of the Maxville. The series comprises the Maxville limestone and the Waverly group, in which is included at the base the Sunbury shale, Berea sandstone, and Bedford shale.

The Maxville limestone shows in all the sections except that of the Blaine Creek well (No. 9). It ranges in thickness from 60 feet in the Summit well (No. 3) to 345 feet in the Alum City Oil Company's Straight Creek well (No. 6) and the A. M. Holbrook well (No. 18). The latter thickness seems excessive, for near both the Straight Creek well and the Holbrook well other records show a thickness of 109 and 152 feet for this limestone. The fact that the unusual thickness of limestone is accompanied by a marked thinning of the underlying Waverly in both records is indirect evidence that the thickness of the limestone has been overestimated. The Richardson well (No. 5) shows the next lower measurement—about 270 feet. But this, too, may be excessive, for the Catletts Creek well, not over 3 miles away, shows

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only 80 feet of limestone. The limestone shows great variation and no tendency to thicken regularly in any part of the area. Whether or not this is due to an unconformity at its top can not be stated, but it is known that an unconformity exists between the Mississippian and Pennsylvanian series in Pennsylvania and West Virginia. The Maxville limestone is the "Big lime" of the Pennsylvania drillers and corresponds to the Greenbrier of West Virginia.

The Waverly group includes the Mississippian rocks below the Maxville limestone and above the Devonian shale. At the top of this group, in the wells studied in the northern part of the quadrangle, a persistent sandstone is present. It is in places overlain by a shale bed that is usually thin, but is 40 feet thick in the Joshua Kelly well (No. 1). At Straight Creek and on Glancy Fork no sandstone appears in this position, but the Horseford Creek well (No. 10) shows 95 feet. In the Blaine Creek section 370 feet of white sandstone and conglomerate are represented in this part of the section, and without doubt part of this thickness is the upper sandstone of the Waverly. In the wells in the southern part of the quadrangle it is usually absent, except in the Jason Boggs well (No. 11), where the sandstone in this position measures 345 feet, with the underlying shales only 75 feet thick. This interpretation of the lithologic character of the rocks is open to some question, as the shale below the sandstone is everywhere much thicker than the sandstone itself. In a carefully kept record of the Guffey well, north of Grayson, no typical sandstone is reported from this position. The complete record of the well, which seems to be the only one known in this particular part of the quadrangle, is given to show the character of the underlying formations in this part of Carter County.[a]

Log of Guffey well, just north of Grayson, Carter County, Ky.[b]

	Thickness.	Depth.
Carboniferous:	*Feet.*	*Feet.*
Quicksand	28	28
Slate, black	30	58
Sandstone	12	70
Slate, black	10	80
Limestone, Maxville	20	100
Shale, dark green, sandy	230	330
Slate, light gray, and sand shells	270	600
Sandstone and shale	50	650
Sandstone, slate, and shells	85	735
Slate, black (Sunbury shale)	22	757
Sand, Berea (oil and gas)	112	869
Slate, gray (Bedford)	25	894
Slate, red (Bedford)	6	900
Devonian shale:		
Slate, black	116	1,016
Slate, white	5	1,021
Slate, black	169	1,190
Slate, white	20	1,210
Slate, black	95	1,305
Slate, white	118	1,423
Limestone (oil and gas) ("Corniferous")	2	1,425
Silurian:		
Limestones, fine and coarse; strong flow of salt water at 1,475 feet	55	1,480

[a] Oil and gas: Kentucky Geol. Survey, Bull. No. 1, 1905, p. 74.

[b] The geologic units were identified by J. B. Hoeing.

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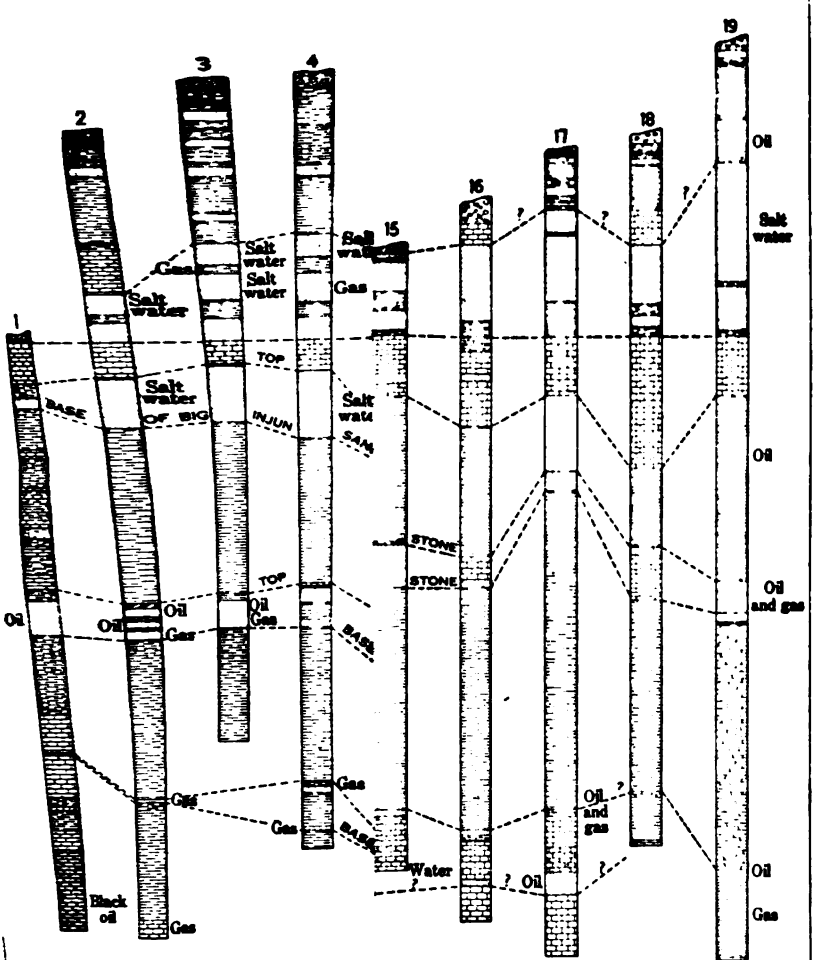

1 Little Sandy Oil Co., Joshua
Euclid, Greenup Co.
2 Clinton well, George farm,
Boyd County
3 Summit well, Summit, Boyd
4 Catletts Creek, 2 miles west
5 Richardson farm well, west
Sandy River, 1½ miles south
(Longabaugh well)
6 Alum City Oil Co., Straight C
7 New Domain Oil and Gas C
Carter County
8 New Domain Oil and Gas C
farm, Glancy Fork, Carter C

VERTICAL SCALE IN FEET
0 200 400 600 800

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In the record of the deep well near Central City, W. Va., the sandstone appears with a thickness of 177 feet, showing its continuation to the east of this quadrangle.[a]

Section of well on Fourpole Creek near Central City, W. Va.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
Carboniferous:		
Conductor		26
Shale and lime (sand?)	94	120
Lime	7	127
Slate and fire clay	98	225
Sandstone	25	250
Shale	50	300
Sandstone	30	330
Slate, black	10	340
Sand, gray	60	400
Slate, black	10	410
Sandstone	85	495
Slate, white and blue	25	520
Sand and lime	20	540
Slate	20	560
Slate, black	175	735
Sandstone, gray	25	760
Slate, black and blue	75	835
Shale and lime	30	865
Sandstone	30	895
Slate, black	40	935
Limestone	5	940
Slate, black	30	970
Limestone (Maxville)	150	1,120
Slate	28	1,148
Sand, gray (Big Injun)	177	1,325
Shale, black	370	1,695
Limestone, hard	10	1,705
Slate, brown	25	1,730
Sandstone	25	1,755
Slate, black	10	1,765
Sand and lime	23	1,788
Slate	6	1,794
Shale, black	20	1,814
Sand, black (Berea)	97	1,911
Devonian:		
Slate	24	1,935
Slate, white	100	2,035
Lime and shale	9	2,044
Slate, black	211	2,255
Slate, brown	55	2,310
Sand and shale	45	2,355
Slate, black and blue	30	2,385
Sand, black	30	2,415
Slate, black	5	2,420
Sand, white	5	2,425
Slate, various colors	325	2,750
Sandstone	5	2,755
Limestone (part of this limestone may be upper Silurian)	215	2,970

[a] This well was drilled in 1898. The record was furnished by Thomas W. Harvey, owner.

The meager data available in this area as a whole indicate a tendency in this sandstone to die out to the south. It is the Burgoon ("Big Injun") sandstone of the Pennsylvania drillers, and probably represents the "Big Injun group" of the Kentucky Geological Survey and the Logan formation of the Ohio Survey. The thickness of the sandstone and shale ranges from 70 to 370 feet.

The underlying shales of the Waverly are from 370 to 470 feet thick across the northern part of the quadrangle, from west to east.

[a] Campbell, M. R., Description of the Huntington quadrangle: Geologic Atlas U. S., folio 69, U. S. Geol. Survey, 1900, p. 3.

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In the wells in the central part of the quadrangle, except the Alum City Oil Company's well at Straight Creek (No. 6, Pl. VI), the thickness is rather uniform, ranging from 375 to 440 feet. It is fairly uniform also along the southern edge of the quadrangle, most of the wells showing about 400 feet. In most of the records the rocks are described as sand and shale, the latter usually light or gray in color, but in places dark or black. Local limestone layers are also recorded.

The Sunbury shale and Berea sandstone, near the base of the Mississippian series, consist of oil- and gas-bearing shale and sandstone from 60 to 200 feet thick. In the northern part of the quadrangle as a whole the Mississippian series averages very nearly 700 feet in thickness, but it shows a tendency to grow thinner toward the south.

DEVONIAN SYSTEM.

The records show, below the shales and sandstones at the base of the Mississippian series, a considerable body of shale, more or less calcareous, in the midst of which occurs a gas- or oil-bearing sand, probably the Ragland sand of the Kentucky drillers. In some wells this sand is underlain by a few hundred feet of black shale (Ohio shale), but in others the underlying rocks are more or less calcareous in part. It is probable that in the wells drilled in the southern part of the area (Nos. 11 to 19) Silurian limestones have been reached. They may also be reached in some of the wells near the northern edge of the quadrangle, as in that at Central City, where a part of the 215 feet of limestone at the base of the section may be Silurian. The basis for this statement lies in the fact that in the vertical section of Ohio rocks the limestones at the base of the Devonian do not exceed 75 feet in thickness at any point.[a] It is also possible that in the wells in the northern part of this area the considerable bodies of shale represented below the Ragland sand may be older than Devonian.

OIL AND GAS WELLS.

On the geologic map accompanying this report two classes of wells are represented by red and green symbols. Those in red indicate wells that are known to have produced gas in quantity; the other wells are shown in green. Nearly all the wells in this area were drilled in search of oil. In some of them oil was found, but in too small amount to pay the expense of prospecting, and some wells were practically dry. The rocks containing oil and gas are usually known to the drillers as sands. Those known to be productive in this area are described in the next section. The numbers in the accompanying list correspond to those used on the economic map (Pl. I).

[a] Rept. Geol. Survey Ohio, vol. 7, 1893, plate opp. p. 4.

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Deep wells in the Kenova quadrangle.

1. Little Sandy Oil Company, Joshua Kelly farm, Euclid, Greenup County.
2. Clinton well, George farm, Shope Creek, Boyd County.
3. Summit, Boyd County.
4. Catletts Creek, 2 miles west of Catlettsburg.
5. Longabaugh well, Richardson farm, west bank of Big Sandy River, 1½ miles south of Catlettsburg.
6. Alum City Oil Company, Straight Creek, Carter County.
7. New Domain Oil and Gas Company, Straight Creek, Carter County.
8. New Domain Oil and Gas Company, L. C. Glancy farm, Glancy Fork, Carter County.
9. Mouth of Blaine Creek, Lawrence County.
10. Horseford Creek, Lawrence County.
11. New Domain Oil and Gas Company, Jason Boggs farm, Canes Creek, 6 miles northwest of Blaine, Lawrence County.
12. New Domain Oil and Gas Company, John Boggs farm, Canes Creek, 4 miles northwest of Blaine, Lawrence County.
13. New Domain Oil and Gas Company, J. F. Cooper farm, Lick Fork of Cherokee Creek, 5 miles northwest of Blaine, Lawrence County.
14. New Domain Oil and Gas Company, J. A. Young farm, Cherokee Creek, Lawrence County.
15. Laurel or Broas well, Lower Laurel Creek, Lawrence County.
16. New Domain Oil and Gas Company, H. H. Gambrill farm, Big Blaine Creek, 1 mile west of Blaine, Lawrence County.
17. Berry well, mouth of Cane Creek, Lawrence County.
18. New Domain Oil and Gas Company, A. M. Holbrook farm, one-fourth mile northeast of Blaine, Lawrence County.
19. Griffith Creek, 7 miles southeast of Louisa, Lawrence County.
20. Oil well, Catletts Creek.
21, 22. Forestdale, Ohio.
23. Frank Crank, Yatesville.
24. George Carter, near Yatesville.
25. Hannah Lackey, near Yatesville.
26, 27. Land & Carter, near Yatesville.
28. Keffer well, Upper Stinson Creek.

OIL AND GAS SANDS.

CARBONIFEROUS ROCKS.

Salt sand.—Fresh water is reported in the Summit well (No. 3), well up in the Carboniferous, 425 feet above the top of the Maxville limestone, and also in the Straight Creek well (No. 6), 441 feet above the same datum plane. The first prominent gas and salt-water horizon occurs in the interval of 250 feet above the Maxville, in the lower part of the Pottsville formation. This salt-water bed probably corresponds in places to the Sharon conglomerate. The oil and salt-water sands are either two or three in number, and may be regarded as the equivalent of the Salt sand to the north in Ohio, but in Washington and Monroe counties, Ohio, the name Maxton sand has been applied to the sand resting directly upon the Maxville lime-

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stone. From this bed the old salt wells on Big Sandy River near Zelda obtained their salt water.

Big Injun sand.—The sandstone containing salt water lying directly below the Maxville limestone, or separated from it by a few feet of shale, belongs to the "Big Injun group," or Logan formation of Kentucky and Ohio. The term "group" is hardly applicable in the Kenova quadrangle, as most of the records show a single sandstone bed from 30 to 175 feet thick. In the Blaine Creek well (No. 4) 370 feet of sand and conglomerate are indicated in this part of the section, but, as has already been pointed out, some of this is probably the Maxville limestone. Nothing but salt water has been reported from this sandstone.

Berea sandstone.—In the rocks below the Big Injun sand an occasional show of oil is reported, but no persistent oil- and gas-bearing rocks are encountered until the drill reaches the Sunbury shale and Berea sandstone. Most of the records studied show between the shale of the Waverly above (Cuyahoga?) and the Devonian black shale below a group of sandstones with shale layers, which are referred to the Sunbury shale and Berea sandstone. In many of the sections the well-defined sandstone occurring below the black shale of the Waverly is without doubt the Berea sandstone proper, but in certain of the sections showing several sandstone bands the boundary has been drawn on the lowermost where there seemed no positive evidence to the contrary. Where a single layer of both shale and sandstone has been recognized in the driller's logs the thickness does not exceed 120 feet. Both oil and gas are reported from the Berea, but in no instance has the production been on a profitable scale.

DEVONIAN ROCKS.

Ragland sand.—The Devonian shale carries some oil disseminated through it, but the first persistent gas- and oil-bearing stratum in this rock is a sandstone band a few hundred feet from its top. Some of the records show this sandstone embedded in shale, as in the Clinton well (No. 2), the Catletts Creek well (No. 4), and the Richardson or Longabaugh well (No. 5); but in others it rests upon or is associated with limestone. It is barely possible that the Ragland sand of the southwestern part of the quadrangle, found resting upon limestone, may not be the same sandstone as the gas-bearing rock of the Catletts Creek and Clinton wells, but the presumption is strongly in favor of this correlation. The reason for this question lies in the fact that in the Clinton, Catletts Creek, and Longabaugh wells the gas-bearing sand is underlain by considerable bodies of shale, which are described in the Clinton record as black and white. In some wells (Nos. 6 and 19) the rock at the Ragland horizon is probably a lime-

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stone. In the wells where this sandstone is underlain by shale (Nos. 2, 4, and 5) rocks earlier than Devonian may be represented. This gas-bearing sandstone, regarded as the Ragland, is in most places a very thin band, but at the John Boggs well (No. 12) and the J. A. Young well (No. 4) it is reported to be more than 100 feet thick. In Bath County in the Ragland field none of the records show a thickness of the oil-bearing stratum greater than 25 feet.[a] This sand furnishes the high-pressure gas on Catletts Creek, but there the sandstone occurs in two benches. At the Jason Boggs well on Canes Creek, Lawrence County, gas containing much hydrogen sulphide was encountered at this horizon, with a rock pressure of 350 pounds.

PRODUCTION.

Most of the wells drilled in this area report a small production of oil and gas, but so small as not to be profitable. Two gas wells are notable exceptions. The well drilled on Catletts Creek struck gas in a 9-foot layer of sandstone, thought to correspond to the Ragland sand, at a depth of 1,979 feet. The pressure recorded was 975 pounds. This gas is now piped to Catlettsburg. At the Jason Boggs well on Canes Creek, Lawrence County, gas was encountered in the interval from 1,672 to 1,697½ feet below the surface; also in the Ragland sand. The volume was reported to be 750,000 cubic feet per twenty-four hours when the gas was tapped, and the rock pressure to be 350 pounds. The gas was heavily impregnated with hydrogen sulphide.

TOPOGRAPHIC DATA.

TRIANGULATION STATIONS.

The topographic work for the map of the Kenova quadrangle is based on triangulation stations, two of which are found within the limits of the quadrangle and several outside of its borders to the north, south, and northwest. The stations north and northwest of the area, some of which are in the State of Ohio, were established by the Coast and Geodetic Survey, to which the writer is indebted for the information regarding them. The four triangulation stations represented south of the area in the accompanying figure were established by the United States Geological Survey. The two stations on this quadrangle are designated by the names Oakland and Buena Vista. Oakland, named from Oakland furnace, on Chadwick Creek, Boyd County, is situated at the highest point on the ridge at the head of Campbell Run and Laurel Creek. Buena Vista, so called from Buena Vista furnace, is situated on the ridge northwest of Straight Creek, on the dividing line between Greenup and Boyd counties. The accompanying figure (21) shows the relative positions of these triangulation stations. Descriptions of their exact locations follow.

[a] Kentucky Geol. Survey, Bull. No. 1, 1905, pp. 59, 60.

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Geographic positions of stations.

[Locality, 39th parallel. United States standard datum. States of Ohio and Kentucky.]

Station.	Latitude.	Seconds in meters.	Longitude.	Seconds in meters.
	° ′ ″		° ′ ″	*Meters.*
Round Top (1885)	38 36 35.371	1,090.7	83 12 37.795	914.5
Oakland (1884)	38 21 46.466	1,432.7	82 38 52.881	1,283.8
Buena Vista (1884)	38 23 44.026	1,357.5	82 48 21.664	525.7
Howland (1885)	38 37 47.115	1,452.8	82 59 20.415	493.7
Fradd (1885)	38 35 46.927	1,447.0	82 33 06.031	145.9
Gould (1885)	38 38 27.582	850.5	82 49 56.728	1,372.0
Scioto (1885)	38 45 47.719	1,471.5	83 03 08.622	87.4
Ironton, cupola of Kelly's house (1885) [a]	38 31 59.67	1,839.9	82 40 10.36	250.9

Station.	To station—	Azimuth.	Back azimuth.	Distance.	Log. distance.
		° ′ ″	° ′ ″	*Meters.*	*Meters.*
Round Top (1885)	Scioto	219 07 22.42	39 13 21.31	21,969.63	4.3418228
	Howland	263 23 19.14	85 31 36.82	19,416.44	4.2881697
Oakland (1884)	Gebhardt	241 41 35.15	61 56 19.22	39,117.34	4.5923693
	Davis	272 40 01.16	92 50 59.31	25,780.11	4.4112848
Buena Vista (1884)	Fradd	224 47 25.11	44 56 55.06	31,451.43	4.4976404
	Oakland	284 39 44.46	104 45 37.60	14,273.64	4.1545347
Howland (1885)	Gould	264 43 17.96	84 49 09.90	13,690.61	4.1364228
	Buena Vista	328 23 44.36	148 30 34.56	30,504.44	4.4843631
Fradd (1885)	Wray	271 00 59.69	91 04 23.75	7,917.68	3.8985980
	Gebhardt	285 51 33.48	106 02 43.60	27,068.65	4.4324666
	Oakland	18 00 13.70	197 56 37.88	27,244.57	4.4352799
	Fradd	281 21 56.10	101 32 26.91	24,947.67	4.3970300
Gould (1885)	Oakland	332 25 05.92	152 31 59.19	34,808.56	4.5416890
	Buena Vista	355 09 35.66	175 10 34.86	27,341.14	4.4368167
	Fradd	292 56 07.10	113 14 50.55	47,235.01	4.6742640
Scioto (1885)	Gould	305 26 57.47	125 35 09.49	23,361.24	4.3684959
	Howland	339 58 48.81	160 01 08.36	15,770.77	4.1978529
	Round Top	39 13 21.31	219 07 22.42	21,969.63	4.3418228
Ironton, cupola of Kelly's house (1885) [a]	Fradd	235 39 56	55 44 20	12,435.5	4.094663
	Oakland	354 19 06	174 19 54	19,000.8	4.278771

[a] No check on this position.

ROUND TOP.

Round Top station is situated in Lewis County, Ky., about 5 miles west of Quincy, on a hill just back of L. Johnson's house, well known in this locality as Round Top and as being the highest point along Ohio River between Pittsburg and Cincinnati. The whole top of the hill was cleared off, with the exception of two pine trees.

The station is marked by an earthen pyramid buried 3 feet in the ground. Above this and coming to the surface is a tile pipe 6 inches in diameter and 2 feet long. This is filled with cement and a nail in the center marks the center of the station. Four tile pipes 2 feet long and 4 inches in diameter, filled with cement, with a nail in the center, were put down as reference marks—north, east, south, and west—their tops being level with the surface of the ground. The following measurements were made with steel tape: From station to nail in pipe north (true), 5.88 feet; to nail in pipe east, 6.22 feet; to nail in pipe south, 5.95 feet; to nail in pipe west, 5.93 feet.

SCIOTO.

Scioto station is on the land of George Davis, about 1½ miles west of his distillery on the west side of Scioto River, which is about 1½

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miles northwest of Portsmouth. A signal 96 feet high to the floor of the scaffold was erected here and theodolite No. 118 was mounted about 100 feet from the ground. Lines were opened to Peach

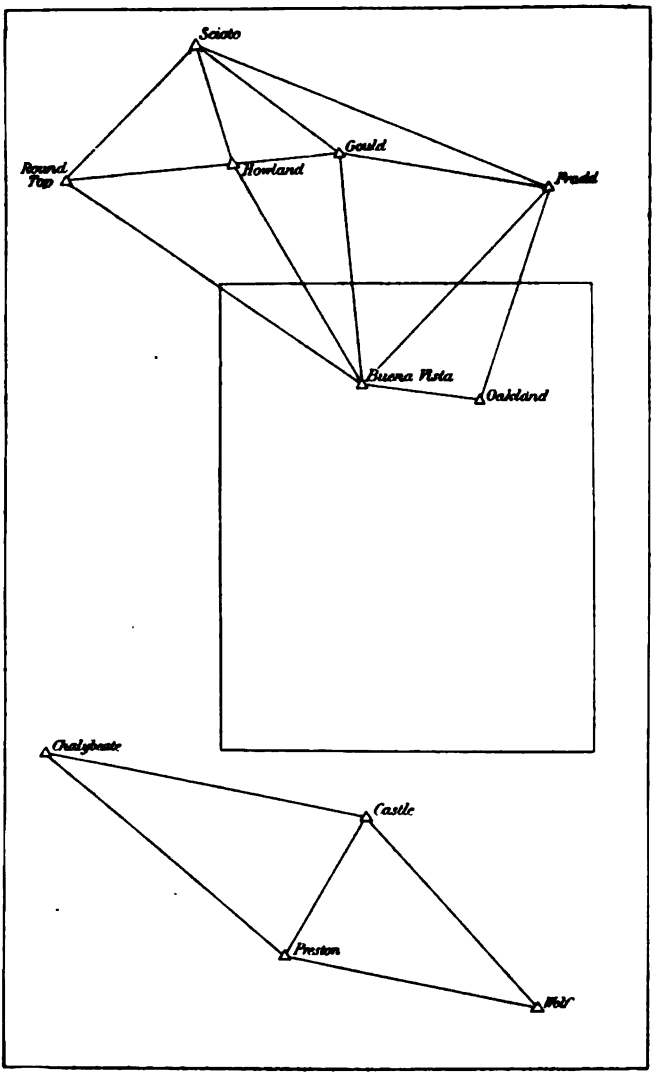

FIG. 21.—Sketch showing location of triangulation stations in and near the Kenova quadrangle.

Mount station (19 miles) by cutting on five ridges, and to Twin Creek station (13 miles) by cutting on two ridges. Fradd, Gould, Howland, Round Top, Springville, and the whole of the city of Portsmouth are open.

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The station is marked as follows: A pottery pyramid was sunk below the surface, over which was placed a 6-inch draintile pipe, 2 feet long, filled with concrete. The center is marked by an iron spike. Reference marks consist of 4-inch pipes, as follows: North, 6.29 feet; south, 6.18 feet; east, 6.25 feet; west, 6.11 feet. These four pipes were filled with concrete, and a nail driven in each marks the center.

HOWLAND.

Howland station is situated in Greenup County, Ky., between Tygarts and Schultz creeks and between Right and Left forks of Beechy Creek, about 3½ miles west of Liberty, about 400 yards northwest of the house of James Howland, on a point of land belonging to James Howe, and about 100 yards west of the main county road that runs from Schultz Creek to the mouth of Brushy Creek. The signal is in sight from Mr. Howland's house. A 65-foot tripod and scaffold was erected here. Theodolite No. 135 was mounted on top of the tripod and the observations were made from it.

The station is marked by an earthen pyramid buried 2½ feet below the surface of the ground; above this is placed a draintile pipe 6 inches in diameter and 2 feet long, the top being just even with the surface of the ground. The pipe was filled with cement and a 6-inch spike in the center marks the station. Four tile pipes 4 inches in diameter and 2 feet long, filled with cement, with a nail in the center of each, were put down as reference marks. The following measurements were made: From station to nail in pipe north (true), 6.45 feet; east, 6.05 feet; south, 5.95 feet; west, 6.10 feet.

GOULD.

Gould station is situated on the hills east of Ohio River, about 1½ miles in an air line from the river at Franklin furnace landing. The land formerly belonged to O. B. Gould, but was sold in 1884 to Means, Kyle & Co., of Hanging Rock, Ohio. The hill is covered with large timber of second growth.

The station is marked as follows: The center by a pottery pyramid sunk 3 feet below the surface; above this is a piece of sewer pipe 6 inches in diameter, filled with concrete, with a nail in its center. Other pieces of sewer pipe, 4 inches in diameter, are sunk at the following distances and directions: North (true), 4-inch pipe, 6.08 feet; south, 4-inch pipe, 6.11 feet; east, 4-inch pipe, 5.78 feet. On the west is a brass rod, one-fourth inch in diameter, driven into the smoothed top of an oak stump and surrounded by a triangle of iron nails, distant 5.77 feet.

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FRADD.

Fradd station is very near to the line between Lawrence and Aid townships, in Lawrence County, Ohio, about 100 yards south of the road running from Marion to Vesuvius furnace, about 3 miles from Marion, nearly a mile west of the white schoolhouse on the hill, on land belonging to Charles Fradd, who lives in the hollow about one-third of a mile southwest of the station.

The station was marked by an earthen pyramid, sunk 2½ feet in the ground; above this was placed a 6-inch tile pipe, 2 feet long and filled with cement; a 6-inch spike marks the station center. Four 4-inch tile pipes, 2 feet long, filled with cement, with a nail in the center, were put down as reference marks, their tops being level with the ground. The following measurements were made: From station center to nail in pipe north (true), 7.63 feet; east, 6 feet; south, 6.50 feet; west, 6 feet.

BUENA VISTA.

Buena Vista station is on the highest point of the narrow ridge about 2½ miles east of Hunnewell furnace, Greenup County, Ky. The county road from Hunnewell furnace to old Buena Vista furnace crosses the ridge, and the station is on the high point to the left of the road, called in the neighborhood the "high knob." When the ridge was cut off for charcoal a single large tree was left, in which a flag was put for use in reconnaissance. This tree was trimmed by cutting its lower branches and was left temporarily for a mark.

The station is marked at the center by a pottery pyramid sunk 3 feet below the surface. Above this was built a pier of concrete, about 4½ feet above the ground, on which was mounted the theodolite. The center of the pier above the station is marked 6 inches below the surface, at 15 inches below the top, at 6 inches below the top, and on the surface of the pier by iron spikes driven into the concrete accurately over the center of the station. A small pole was erected to observe on from Oakland, and was taken down when the pier was built. Reference marks: Two concrete piers, 6 by 6 inches and 2 feet long, with their tops even with the ground and nail in the center, one east, one west; for the north and south marks, oak stubs with nail in the top. The following are the distances: Station to nail north (true), 7.90 feet; east, 7.16 feet; south, 8.03 feet; west, 7 feet. The large chestnut oak in which the flag was placed was cut down and a pole was erected over the pier, with crotch 16 feet high and pole 12 feet above the crotch. The distance from the station to a blazed stump marked with a triangle of driven nails with a spike in the center is 17.3 feet.

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OAKLAND.

Oakland station is on the highest part of the wooded hill at the headwaters of Chadwick Creek, on the land of Thomas Galligher, a few feet from the fence dividing his land from that of James L. Rucker.

The center is marked by a pottery pyramid, buried 3 feet. Over this is placed a section of 4-inch tile pipe 2 feet long, its upper surface level with the surface of the ground. This pipe is filled with and surrounded by concrete made of hydraulic cement and broken sandstone. The station center is marked on the top of the concrete by an iron spike 6 inches long, the center of the head of this spike being accurately plumbed under the center of the tripod head, on which was mounted theodolite No. 118. Reference marks consisting of 4-inch tile pipes 2 feet long, filled with concrete and sunk level with the surface of the ground, with a nail in the center of each, were placed at the following distances and directions: North (true), 5.98 feet; south, 5.02 feet; east, 6.02 feet; west, 6.06 feet.

WOLF.[a]

On sharp ridge at head of Wolf Creek, Martin County, Ky., 12 miles (air line) southwest of Warfield, on Tug Fork of Sandy River. Permanent mark: Large chestnut tree.

[Latitude, 37° 43′ 34″.4; longitude, 82° 34′ 20″.9.]

To station—	Azimuth.			Back azimuth.			Log. distance.
	°	′	″	°	′	″	*Meters.*
Castle	138	37	03.8	318	28	31.8	4.489071
Preston	101	39	08.3	281	26	22.5	4.494856
Frazier	13	12	43.8	193	09	13.7	4.569316
Willard	342	01	58.8	162	08	53.3	4.735622

PRESTON.[a]

On northeast end of Long Knob, at head of Barnett and Jennie and Little Paint creeks, Johnson County, Ky., 7 miles southwest of Paintsville.

[Latitude, 37° 46′ 57″.3; longitude, 82° 55′ 11″.6.]

To station—	Azimuth.			Back azimuth.			Log. distance.
	°	′	″	°	′	″	*Meters.*
Wolf	281	26	22.5	101	39	08.3	4.494856
Quicksand	1	28	02.2	181	27	41.1	4.520126
Frazier	332	14	31.1	152	23	43.8	4.679871

[a] This description may be found in Bull. U. S. Geol. Survey No. 122, 1894, p. 82.

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SPIRIT-LEVEL WORK.

During the course of topographic work in the Kenova quadrangle numerous bench marks were established, descriptions and elevations of which are given below.

The elevations in the following list are based on a bronze tablet at Kenova, W. Va., in the west side of the door sill at the entrance to the men's waiting room at the union station. The elevation of this tablet is accepted as 566.918 feet above mean sea level. The initial height from which these elevations are derived is that determined for bench mark 316 A of the Ohio River Survey, Corps of Engineers, U. S. Army, at Catlettsburg, Ky., by the 1903 adjustment of precise leveling. The leveling was done in 1900 under the direction of W. N. Morrill, topographer; by J. E. Buford and C. H. Semper, levelmen. All standard bench marks dependent on this datum are stamped with the letter "K" in addition to the figures of elevation.

HAVERHILL, OHIO, TO GREENUP, KY.; THENCE ALONG EASTERN KENTUCKY RAILWAY TO ARGILLITE.

	Feet.
Greenup County building, clerk's office; bronze tablet set vertically in stone step at right of entrance, stamped "538 I"	540.004
Riverton, 1.5 miles south of, railroad bridge 150 feet south of road crossing, on abutment at southwest corner of bridge; chisel mark	554.70
Argillite, 1,320 feet south of, east side of north end of Argillite tunnel, 8.86 feet higher than top of rail, in sandstone ledge; bronze tablet stamped "567 K 1900"	566.442

GREENUP SOUTHWARD TO MOUTH OF WHETSTONE CREEK.

Greenup, 2.5 miles southwest of, 750 feet southwest of log house, on north side of road, north of road center, in south end of sandstone bowlder 7 by 10 by 25 feet; bronze tablet stamped "578 I"	580.081

KENOVA ALONG CHESAPEAKE AND OHIO RAILWAY (BIG SANDY DIVISION) TO ROCKVILLE (BUCHANAN), KY.

Savage, 2.6 miles north of, on west side of highway or crossing 40 feet from center of track and 10 feet from center of highway, on sandstone ledge; chisel mark	552.44
Savage, 870 feet north of station, at southeast corner of highway bridge, on bridge seat; chisel mark	541.26
Savage, in front of station; top of west rail	547.1
Savage Branch station, 1 mile south of, at David Lockwood's house, in foundation on left side of front steps; bronze tablet stamped "586 K"	586.113
Lockwood, in front of station; top of east rail	544.3
Kavanaugh Church, in front of flag station; top of east rail	581.3

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BOLTS FORK NORTHWARD VIA CANNONSBURG TO ASHLAND.

	Feet.
Bolts Fork, 600 feet north of post-office, highway bridge over Bolts Fork, at southeast corner bridge seat; bronze tablet stamped "652 K"	652.567
Mavity, 0.8 mile north of, at forks of road 105 feet south of log house, 51 feet south of sycamore, on abutment at southeast corner of bridge; chisel mark	605.08
Cannonsburg, post-office building, southeast corner of, 93 feet from railroad crossing; bronze tablet stamped "604 K"	604.871
Mead station, 0.5 mile south of, on Ashland Coal and Iron Railway, 200 feet southwest of house on west side of road, corner stone west end of culvert; chisel mark	590.92
Mead station, 1 mile north of, 81 feet north of small bridge, 15 feet east of center of road, in sandstone bowlder; bronze tablet stamped "638 K"	639.221
Ashland, Chesapeake and Ohio station, on Carter avenue, between Twelfth and Thirteenth streets, south side of building, 2 feet above ground; bronze tablet stamped "556 K"	556.531

ASHLAND ALONG CHESAPEAKE AND OHIO RAILWAY VIA CATLETTSBURG TO HAMPTON.

Ashland, 1.5 miles east of, on Chesapeake and Ohio Railway, girder bridge over electric railway, on top stone at south end of west wing wall; chisel mark	555.74
Catlettsburg, Louisa street, between Franklin and Clay streets, in court-house yard, at northwest corner of clerk's office, 1 foot above water table; aluminum tablet stamped "549 K 1900"	550.303
Catlettsburg, Big Sandy National Bank (U. S. Engineer's bench mark "316 A"), on window sill; chisel mark $B \frac{U}{S} M$	548.690

BUCHANAN WESTWARD TO MAYHEW.

Buchanan, in front of station; top of east rail	558.3
Buchanan, 150 feet south of, overhead railway bridge (B. S. 189), in top stone at east end of north pier; bronze tablet stamped "554 K 1900"	554.231
Mayhew, 850 feet west of post-office, at northeast corner of bridge over Bolts Fork, 4 feet lower than bridge, on bridge seat; chisel mark	682.18

BUCHANAN SOUTHWARD ALONG CHESAPEAKE AND OHIO RAILWAY (BIG SANDY DIVISION) TO GALLUP.

Buchanan, 1.7 miles south of, trestle No. 206, in guard rail at southeast end; top of bolt	563.03
Fuller, 300 feet north of station, 5 feet west of railroad at east edge of highway, 30 feet north of white house, in sandstone ledge; bronze tablet stamped "572 K 1900"	570.874
Poters, in front of station; top of rail	573
Louisa, U. S. Engineers' bench mark No. 13 Big Sandy, at Lock No. 3, in engineers' office yard	569.081
Louisa County court-house, north face, west side, in foundation; aluminum tablet stamped "584 K 1900"	582.419

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	Feet.
Gallup, at G. C. McClure's house, in stone step to house; bronze tablet stamped "591 K 1900"	589.370
Gallup, 0.6 mile west of, U. S. Engineers' bench mark No. 5 Big Sandy, 50 feet south of west end of trestle No. 403	590.289

GALLUP WESTWARD TO PROSPERITY.

Adams, 2 miles south of post-office, at M. R. Hayes's residence, in southwest corner of foundation; bronze tablet stamped "667 K 1900"	666.591

IRAD NORTHWARD 5 MILES, THENCE SOUTHEASTWARD VIA YATESVILLE TO LOUISA.

Yatesville, 3 miles northwest of, in field on south side of and 45 feet from center of road, 135 feet from southwest corner of Green Valley schoolhouse, in north side of large sand rock; bronze tablet stamped "598 K 1900"	596.856

MAYHEW WESTWARD TO DENTON, THENCE NORTHEASTWARD ALONG ASHLAND COAL AND IRON RAILWAY TO PRINCESS, THENCE EASTWARD TO CANNONSBURG.

Denton, 4.5 miles east of, on top of hill 60 feet north of road, at old road going north, old abandoned frame house, on foundation at southeast corner; chisel square	905.39
Denton, Chesapeake and Ohio Railway station, 200 feet northeast of, 16 feet east of center of main track, in top stone; chisel mark	669.84
Denton, 1.5 miles east of, 200 feet north of road crossing at southwest end of Means tunnel on Ashland Coal and Iron Railway, 15 feet west of highway, in sandstone ledge; bronze tablet stamped "787 K 1900"	787.794
Grant station, at southwest corner of girder bridge No. 11, 30 feet west of switch stand near station, on bridge seat; chisel mark	685.92
Geigersville, 800 feet north of Rush post-office, 600 feet south of coal dump, 330 feet south of road crossing, at southwest corner of railroad bridge No. 10, in bridge seat; bronze tablet stamped "639 K 1900"	639.442
Coalton station, west of tool house near, at northeast corner of railroad bridge No. 6, in bridge seat; chisel mark	615.03

ARGILLITE SOUTHEASTWARD VIA NAPLES TO PRINCESS.

Naples, 1,300 feet north of post-office, at southwest corner of overhead highway bridge across East Fork on or near Boyd-Greenup county line, in bridge seat; bronze tablet stamped "571 K 1900"	570.839
Princess, 3.25 miles northwest of, at northeast corner of highway bridge over Williams Creek, east of log house, on abutment; chisel mark	571.67

ARGILLITE SOUTHWESTWARD VIA OLDTOWN AND EUCLID, THENCE NORTHWARD TO HEAD OF CLAYLICK CREEK (SINGLE-SPUR LINE.)

Oldtown, Mrs. Womack's house, 350 feet north of Oldtown Creek bridge, on west side of road, in foundation stone on east side of house, 6 feet from southeast corner; bronze tablet stamped "558 K 1900"	556.843
Claylick Creek, head of, on ridge where road turns to right to go down creek, near site of former schoolhouse, on north side of road between J. H. Hally's and W. J. Hally's, in ledge; bronze tablet stamped "957 K 1900"	956.345

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OLDTOWN SOUTHWARD TO HOPEWELL, THENCE SOUTHWARD ALONG EASTERN KENTUCKY RAILWAY TO GRAYSON.

	Feet.
Grayson, 0.4 mile west of railroad, at southeast corner of foundation of court-house; aluminum tablet stamped "686 K 1900"	684.996

GRAYSON EASTWARD VIA SENEY TO KILGORE.

Grayson, 5.6 miles east of, on north side of road, 15 feet from center, near top of Crib Hill, in sandstone ledge; bronze tablet stamped "834 K 1900"	832.874
Kilgore, 1.3 miles west of, in road between W. C. Hargio's residence and the old store of Norton Iron Works, on sandstone bowlder; chisel mark	661.34

GRAYSON SOUTHWARD ALONG EASTERN KENTUCKY RAILWAY TO WILLARD.

Grayson, 0.5 mile south of, at southeast corner of railroad bridge over Little Sandy River, on abutment; chisel mark	588.69
E. K. Junction, 0.5 mile east of, at southwest corner of Chesapeake and Ohio Railway bridge No. S442, on bridge seat; chisel mark	604.03
Willard, 3 miles north of, 6 feet from southwest corner of railroad bridge No. 9, on abutment; chisel mark	613.60
Willard, 1,400 feet east of station, at northeast corner of railroad bridge No. 15 over Dry Fork, in bridge seat; bronze tablet stamped "625 K 1900"	624.462

WILLARD SOUTHEASTWARD ALONG EASTERN KENTUCKY RAILWAY TO WEBBVILLE, THENCE SOUTHWARD ALONG PUBLIC ROAD VIA IRONTON HILL TO BLAINE.

Webbville, 5.8 miles south of, south of small house near south forks of road, on west side, 30 feet from center, in sandstone ledge; bronze tablet stamped "916 K 1900"	914.926
Cherokee, 0.5 mile north of mouth of Cherokee Creek, east of road, south of small house, in sandstone ledge; bronze tablet stamped "646 K 1900"	645.587

BLAINE WESTWARD ALONG BLAINE CREEK TO MARTHA, THENCE NORTHWARD VIA SARAH TO WILLARD.

Blaine, 0.3 mile west of, at northwest corner of highway bridge over Blaine Creek, on bridge seat; chisel mark	655.94
Martha, 0.4 mile north of, on east side of road, 25 feet higher than road, 36 feet north of oak tree on same side of road, in sandstone ledge; bronze tablet stamped "736 K 1900"	735.554
Fielden, 2 miles east of, at Pennington's store, mouth of Hurricane Creek, W. L. Pennington's house on south side of road, in foundation under northeast corner; bronze tablet stamped "698 K 1900"	696.921
Willard, 5 miles southwest of, on west bank of Little Fork, 0.5 mile north of Levi Pennington's, in sandstone ledge between public road and creek; bronze tablet stamped "650 K 1900"	649.725

BLAINE CREEK NORTHEASTWARD VIA PROSPERITY TO IRAD.

Irad, 2 miles west of, 0.25 mile east of log schoolhouse, on north bank of Blaine Creek, south side and 5 feet from center of road, west of house near, in large sand rock; bronze tablet stamped "630 K 1900"	629.784

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 350

GEOLOGY
OF THE
RANGELY OIL DISTRICT
RIO BLANCO COUNTY, COLORADO

WITH A SECTION ON THE WATER SUPPLY

BY
HOYT S. GALE

WASHINGTON
GOVERNMENT PRINTING OFFICE
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GEOLOGY OF THE RANGELY OIL DISTRICT, RIO BLANCO COUNTY, COLORADO, WITH A SECTION ON THE WATER SUPPLY.

By Hoyt S. Gale.

INTRODUCTION.

LOCATION OF THE FIELD.

The Rangely oil field is situated in Raven Park, in the extreme northwestern part of Rio Blanco County, Colo. It lies a short dis-

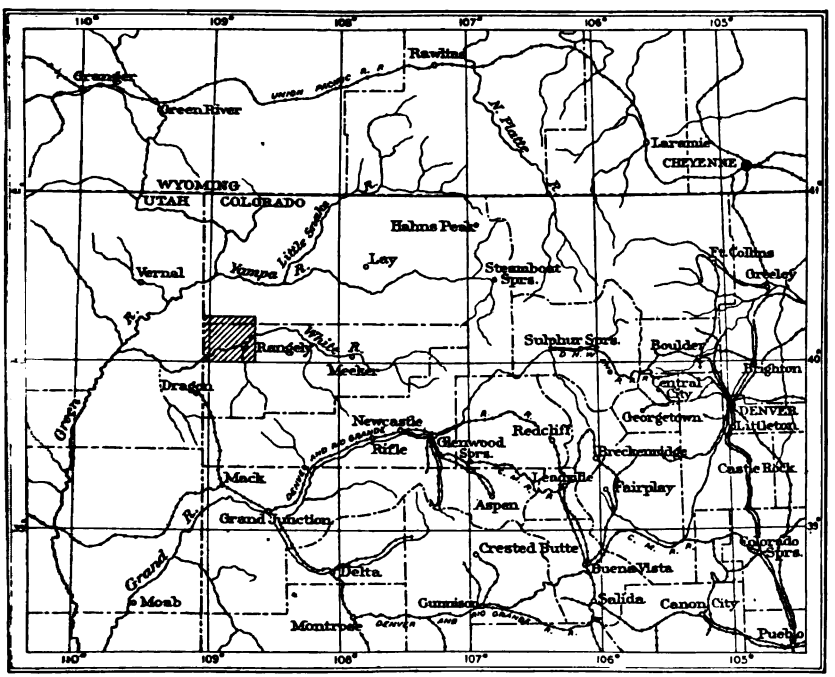

FIG. 1.—Index map showing location of Rangely oil district.

tance north of the Colorado base line, which is approximately the fortieth parallel, and 10 to 15 miles east of the Colorado-Utah line. (See fig. 1.) The field occupies a basin which is a broadened portion

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of the lower White River valley. It is included within the block of townships 1, 2, and 3 north of the base line in ranges 101, 102, and 103 west of the sixth principal meridian. Rangely post-office, from which the oil field takes its name, is the center of the scattering settlement along the immediate valley of the river, which skirts the southern margin of the basin. The post-office is about 33 miles from Dragon, Utah, the present terminus of the Uintah Railway. The trip from Dragon to Rangely can be readily accomplished in a single day, but must now (summer, 1907) be made by private conveyance, as no regular means of transportation is provided. Stage and principal mail connections from Rangely are by way of Meeker, the county seat of Rio Blanco County, which is 60 miles distant by road up the White River valley. A stage runs from Meeker to Rifle, a station on the Denver and Rio Grande Railroad, about 45 miles farther on. The whole trip from Rangely to the railroad by way of Meeker occupies about two and one-half days of actual travel, not including probable delays incident to the stage connections.

SCOPE OF THE PRESENT REPORT.

Present interest in the Rangely district centers mainly in its prospective development as an oil field. The intelligent study and exploitation of its oil resources must of necessity be based primarily on a knowledge of its geologic structure and rock formations. The field has already been described in the reports of the early geologic exploration of this general territory. The keen observation and admirable descriptions of C. A. White, who as geologist of the Hayden Survey studied this district in the early seventies, have appealed strongly to the popular understanding and have gained ready acceptance as a basis for the interpretation of many later problems of the field.

The present report is intended as a review of the geology of the field in greater detail than was possible in the early exploration and reports. It is also the purpose herein to discuss the conclusions reached in that earlier work and to correct some misinterpretations which are now widespread and probably originated there. The extension of detailed geologic study in Cretaceous and Tertiary strata of the Rocky Mountain and Plateau provinces in the last few years by various field parties of the Geological Survey has made available much additional evidence bearing on the general problems of the geologic history of these regions.

The maps (Pls. I, II, in pocket) are new and more accurate and detailed than any hitherto available. The structure sections (Pl. III, p. 34), though necessarily based largely on theoretical assumptions, are nevertheless carefully worked out from all the evidence available and are thought to be good representations of the relative thicknesses and structure of the stratigraphic formations that underlie this district.

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It is hoped that the description and discussion given herein may prove to be of practical value in the economic development of the field. It is beyond the scope of this paper to make any specific predictions as to sites or possible productiveness of wells. The chief purpose, as suggested by the title of the paper, is to present a study and discussion of the geology of the district in which the oil has been found.

FIELD WORK.

The field work which forms the basis of this report occupied a period of about one month in August, 1907. The primary object of the work in this region was an investigation of the coal fields in this part of the State, for the purpose of determining their probable extent and value and of making a classification of the public lands. The topographic and geologic mapping is the work of John Allen Davis, Charles W. Stoops, and the writer.

TOPOGRAPHIC MAP.

The topographic map (Pl. I) which accompanies this report and serves as a base for the geologic mapping is a part of a larger map now (December, 1907) in course of preparation, intended for publication in a report on the coal fields of this general region. The amount and character of the surface relief of the region are represented by contours, or lines of equal elevation, spaced at vertical intervals of 100 feet. These were drawn in the field and to a large extent the sketching was done from the land-survey lines and corners. All the section corners that were found are shown by a symbol on the map, so that some estimate may be made of the relative accuracy of the sketching and locations by noting the corners and lines from which the information was obtained. In addition to the sketching and retracing of section lines, a number of the main roads of the district were traversed with plane table, this work being tied to land-survey corners, with intersections and angles of elevation recorded to prominent points for control.

The recently completed resurveys of the land subdivision lines were found to be in most satisfactory condition, so far as they could be checked by the methods employed during the present work. Most of the corners along the lines traversed were readily found and fairly well marked. It is to be regretted, however, that some of the monuments or corner stakes and markings are not of a more durable character and in a more permanent form. The well-established lines of this new land survey formed an excellent base for the horizontal control of the map here presented. These lines have been plotted according to the standard polyconic projection, with due allowance for convergence and curvature for the scale adopted at the given latitude.

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The Colorado base line is approximately the fortieth parallel. The latest survey of this base line is a reestablishment of the older surveyed line, replacing the old corners by the present ones, which are set at 1-mile intervals according to the last and presumably most correct measurements.

Elevations shown on the map are based on and corrected to two lines of railroad surveys and levels, which traverse the Rangely district from east to west, one extending down White River and the other crossing by way of the longitudinal valley at the southern foot of Blue Mountain.[a] In order to record these data the alignments are shown on the map, together with the elevations given at various points along them. With future and more carefully adjusted work it will doubtless be found necessary to apply some minor corrections to the elevations that are given here, but in view of the somewhat incomplete connections with any well-established datum that are now obtainable no attempt has been made to revise the figures of the original survey. The following checks are obtained at the points named, which are independent and situated at either end of the line used:

Elevations at Newcastle, Colo., and Green River, Utah.

	Colorado Midland Railway survey via White River.	Denver and Rio Grande Railroad levels.[a]	Denver, Northwestern and Pacific (Moffat) Railway survey, corrected to Denver.	Evident correction.
	Feet.	*Feet.*	*Feet.*	*Feet.*
Newcastle	5,570	5,552	----------	−18
Green River, Utah, mouth of Ashley Creek, water levels	4,728	----------	[b]4,715	−13

[a] Gannett, Henry, Dictionary of altitudes in United States, 4th ed.: Bull. U. S. Geol. Survey. No. 274, 1906.
[b] Approximate.

The sketching of topography throughout the rest of the field is based on elevations determined by aneroid barometers.

GENERAL DESCRIPTION.

LOCALITY NAMES AND SETTLEMENT.

The Rangely Basin was first called Raven Park by C. A. White, who as geologist of the Hayden Survey visited the region in 1875. As a topographic basin it presents a curious contrast to the surrounding broken and more rugged country. The district as an oil field is

[a] Routes were surveyed through the Raven Park district in December, 1886, and January, 1887, also in July, 1887, by the Colorado Midland Railway, to whose courtesy the writer is indebted for the use of the survey notes. Acknowledgment is also due to Mr. F. F. Mallon, of Colorado City, Colo., for his kindness and assistance in looking up these old records.

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now more generally known as the Rangely Basin, from the post-office located there. White defines the term "park" in the introduction to his report,[a] and according to that definition his use of the term to describe the White River valley at Rangely is correct. According to popular usage in the Rocky Mountain region, however, the term perhaps implies somewhat of the picturesque quality, a park being an open glade or valley surrounded or partly inclosed by timbered hills. With such a meaning the term would hardly be appropriately applied to the Rangely Basin. This basin is in truth a desolate waste of dry washes and almost barren clay ridges, except only the immediate valley bottoms of White River. There is probably but little change since the time of the Hayden Survey, beyond the establishment of scattering ranches along the river flats. A few wagon trails and wood and coal roads lead out over the ridges or among the well-drillers' camps and these, with an idle derrick or two and well-drillers' cabins, are the only present signs of habitation.

OUTLINE OF THE BASIN.

The Rangely Basin is irregularly oval in outline, its longer diameter extending from northeast to southwest with a total length of about 15 miles. The low valley portion, or Raven Park, has an approximate width of about 5 miles. The valley itself is bordered by an escarpment rim, averaging about 500 feet in height, which presents a steep scarp or cliff facing inward toward the basin center. This innermost escarpment edge is locally known as the "rim rock" and is easily recognized as the upper limit or cap rock of the oil-bearing shale, from which the park has been eroded. Beyond the "rim rock" the ridges dip away in more gradual slopes, rising in successive steps upon cliffs of the higher sandstone strata. Higher steep escarpment bluffs above and beyond the "rim rock" face inward in concentric arrangement rudely parallel to the margin of the park. Sharp rocky canyons intersect the surrounding ridges, draining into the central valley.

DRAINAGE.

White River enters the park through a canyon at its southeast extremity, flows along the southern margin, and leaves again by another canyon. Below the park the river flows continuously in a deepening canyon for the remainder of its course in Colorado. Raven Park thus lies for the most part north of the river valley. Besides the river itself one perennial stream enters the park from the south. This is Douglas Creek, which drains an extensive area south of White River. Its headwaters reach back to the divide between White and Grand rivers along the summit of the Roan or Book Cliffs Plateau. North of

[a] Report on geology of a portion of northwestern Colorado: Tenth Ann. Rept. U. S. Geol. and Geog. Surv. Terr., 1878, pp. 9.

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White River the principal drainage is a wet-weather stream known as Stinking Creek, originally named Unga-too-roosh on the Hayden maps. This, like most of the other drainage channels of the region, is dry most of the summer except immediately after heavy showers, when it runs full with thick muddy water for a few hours only. All these waters are heavily charged with alkaline salts.

SURFACE AND VEGETATION.

The dry, hard soil supports but little vegetation. The clay ridges are sparsely covered with the interminable sage, greasewood, and prickly pear. Along the immediate channels of the dry washes the same shrubs are found in thicker growth. The ground absorbs but little water even after the occasional floods of the summer storms. In heavy showers the water barely wets the top of the ground, running off rapidly and leaving the surface to harden again and crack in the dry air. Lack of water supply, absence of feed for cattle or horses, and the general destitute character of the region as a whole had caused but little value to be attached to the land until the existence of oil was discovered seven or eight years ago.

ROCK FORMATIONS.

GENERAL SUMMARY.

The rocks exposed in the vicinity of the Rangely field represent a large interval in the geologic time scale. On the great axes of uplift that form a part of the Uinta Mountain system north and northwest of Raven Park erosion has exposed the oldest rocks that occur in the region. On the southern flanks of Blue Mountain rocks as low as Carboniferous are brought to view, and from Blue Mountain southward a thickness of more than 7,500 feet of tilted Mesozoic strata is exposed in detail. These beds overlie the incompletely exposed section of Paleozoic rocks and in turn are covered by a similar thickness of Tertiary strata toward the south. The following list of formations and periods is given to outline the groups into which these strata are subdivided for purposes of description:

Summary of formations exposed in the Rangely district as represented on the geologic map (Pl. II, in pocket).

Period.	Formation.	Derivation of the formation names.
Tertiary	Green River Wasatch	King, Powell, and Hayden reports.
	(Unconformity.)	
Cretaceous	Mesaverde formation Mancos shale	Cross, southwestern Colorado reports.
	Dakota sandstone	Meek and Hayden and others.
Jurassic	" Flaming Gorge " " White Cliff "	Powell, Geology of Uinta Mountains.

A discussion of the occurrence of the Rangely oil is directly concerned only with the Cretaceous formations of the preceding table.

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For this reason the descriptions here given are largely confined to these formations and include only brief mention of such strata above and below as naturally fall within the field included by the geologic map. It is the intention of the author to present a fuller discussion of the more complete stratigraphic section in a later paper.[a]

PRE-CRETACEOUS ROCKS.

Immediately below the Dakota sandstone is a mass of variegated badland-forming shale and clay, including some harder beds of limestone and sandstone, together with a peculiar dark cherty, siliceous conglomerate almost exactly like that commonly found with the Dakota formation above. The shale or marl is prevailingly of greenish and pinkish shades, with some beds that weather yellow. The lower 100 to 150 feet of this formation is composed of darker-colored beds, fine greenish sandstone and calcareous rock. Limestone layers composed largely of shells are present near the base, although the general character of the beds seems to indicate much limy or marly material throughout. These beds have an approximate thickness of 800 feet, as measured near the base of Blue Mountain. They are well represented in the excellent exposures on the steep northern slopes of the Dakota hogback in that locality, the more resistant sandstones of the Dakota formation capping and preserving from erosion the upper members of these weaker beds. The lower beds almost invariably form valleys, and as they are usually tilted at considerable angles, their outcrop is a relatively narrow strip between inclosing ridges. The lower strata of these variegated beds are of marine origin, as shown by the fossils they contain; the upper part, by analogy with other and better-known sections, is supposed to be composed largely of fresh-water deposits.

The variegated and shaly beds are limited at the base by a second group of sandstones which, like the Dakota, usually forms a steep rocky ridge. This group is more completely composed of sandstone than the Dakota, and is even more conspicuous as a ridge maker. It is usually very white and massive and cross-bedded to an extreme degree.

The variegated beds are of Jurassic age and probably correspond in their upper or supposedly fresh-water part to the Morrison formation east of the Rocky Mountains. They have also been variously named "Flaming Gorge," McElmo, and in part Gunnison in the Uinta Mountain and western Rocky Mountain regions. The relations of these formations are indicated in the correlation table on page 27. The cross-bedded white sandstone is also of Jurassic age, as is shown by fossils obtained from this field. It is with little doubt the equiva-

[a] Coal fields of northwestern Colorado and northeastern Utah: Bull. U. S. Geol. Survey (in preparation).

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lent of the "White Cliff" sandstone mapped by Powell on the north side of the Uinta Mountains, and also seems to be with almost equal certainty equivalent to the La Plata sandstone[a] of the southwestern Colorado sections. The following fossils were collected from these formations during the last season, and are considered to prove conclusively the Jurassic age of the beds in which they were found. All are of marine types, being from the basal portion of the variegated beds and from the upper half of the cross-bedded white sandstone.

Fossils collected from the Jurassic rocks north of Raven Park.[b]

Variegated beds:
- Ostrea sp.
- Ostrea strigilecula White.
- Eumicrotis curta (Hall).
- Tancredia (?) inornata Whitfield.
- Astarte sp.
- Belemnites densus M. and H.

Cross-bedded white sandstone:
- Trigonia quadrangularis H. and M.
- Tancredia sp.

The principal economic interest that has as yet been attached to these beds is due to the occurrence of deposits of ores of uranium and vanadium in the massive cross-bedded sandstone. These deposits have been elsewhere described.[c] A single observed occurrence of a bed of hard black carbonaceous material which is probably an impure coal has been found in Red Wash Creek where its channel cuts the ledges of cross-bedded Jurassic sandstone, the bed outcropping among the upper members of that formation. The coal is 2 to 3 inches thick and only slightly weathered, occurring at water level in the rather badly disintegrated sandstone. Although very poorly exposed, it is apparently interstratified with the sandstone itself. The analysis of this material has given the following results:[d]

Contains less than 1 per cent of matter soluble in carbon disulphid and does not soften in flame; therefore is not gilsonite or related hydrocarbon. As a coal it has approximately the following composition:

Analysis of coal from Red Wash Creek.

Moisture	10.5
Volatile matter	42.9
Fixed carbon	42.0
Ash	4.6
	100.0

[a] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and Utah: Jour. Geology, vol. 15, 1907, p. 642.

[b] Determinations by Dr. T. W. Stanton; collections now in United States National Museum.

[c] Contributions to Economic Geology, 1907: Bull. U. S. Geol. Survey No. 340, 1908, pp. 257–262.

[d] Analysis No. 2262 by E. C. Sullivan, in the chemical laboratory of the United States Geol. Survey.

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DAKOTA SANDSTONE.

The Dakota sandstone does not come to the surface in Raven Park, but is well exposed in the foothill ridges at the southern edge of Blue Mountain, a few miles farther north. This formation lies at the base of the oil-bearing shale and has been supposed by many interested in the development of this field to offer highly favorable conditions for the storage of large bodies of oil. It has thus been the objective point for most of the deeper wells drilled in this field.

The remarkable persistence of its lithologic character and its continuity of exposure over such extensive areas have led to the acceptance of the Dakota sandstone as a key rock for the correlation of widely distributed stratigraphic sections of the Mesozoic rocks, both above and below that horizon. Few fossils have been obtained from it in the territory adjacent to the Rangely field, and its recognition there is based on tracing from other fields, on its position immediately below the abundantly fossiliferous lower Mancos (Benton) shale, and on the lithologic constitution of its beds, which correspond to those widely accepted as characteristic of the Dakota.

Although the details of the formation exposed at the southern foot of Blue Mountain can hardly be expected to correspond precisely to those of the formation as it lies underneath the Rangely field, a description of the Blue Mountain section contains the best available estimate of the character and thickness of these beds than can now be had. The following measurements were made of the tilted strata exposed near the headwaters of Willow Creek, one of the principal tributaries of Stinking Creek, in the NW. ¼ SE. ¼ sec. 12, T. 3 N., R. 103 W.

Section of Dakota sandstone at Willow Creek.

	Feet.
1. Sandstone, weathered brown (overlain by dark-gray and black slaty shale, supposed to represent the base of the Mancos [Benton])	10
2. Shale with beds of white clay and a hard siliceous conglomerate; shale very black and slaty near its base	110
3. Sandstone, white, cross-bedded, containing conglomerate layers	40
4. Interval, probably shale, covered by sandstone slide-rock	180
5. Sandstone	3
6. Shale, variegated in colors of pink and green, containing also one or more beds of dense reddish-purple limestone	95
7. Conglomerate, of coarse, perfectly rounded pebbles in a scant sandy matrix; pebbles largely of chert and siliceous material	45
	483

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Doctor Stanton has expressed the opinion that Nos. 4 to 7 of the Willow Creek section as indicated above may be found to be older than the Dakota. He says "the variegated shale (No. 6) suggests the Morrison or possibly the Fuson of Darton's Black Hills section." If this opinion is correct the massive conglomerate stratum so naturally included in the base of the Dakota may really be a part of the underlying Jurassic formations and not Dakota at all. This view is given only as a tentative suggestion.

The Dakota outcrop extends westward from the Willow Creek locality continuously, with much uniformity in character and thickness, to and beyond the Colorado-Utah boundary. It there forms a steep, rocky ridge whose summit is composed of the heavy basal stratum of coarse conglomerate, resting immediately upon the variegated clay of the underlying Jurassic. East of the Willow Creek locality the coarse basal conglomerate is found as far as Red Wash Creek, beyond which it is thin or wanting entirely. Near Three Springs, about 15 miles east of Willow Creek, the whole Dakota formation is thin, being apparently represented by an outcrop of two inconspicuous sandstone beds, each not over 10 feet in thickness, separated by an interval of shale.

The only fossils that were found in these beds consist of a few very indistinctly preserved leaves. These were collected in a prospect pit exposing a black carbonaceous shale included between the massive white sandstones near the top of the formation. The pit is situated in the SE. ¼ sec. 5, T. 3 N., R. 101 W., just north of the Yampa River and Vernal wagon trail and near the headwaters of the west fork of Red Wash Gulch. The specimens collected could not be identified, but the locality may serve as a guide in further search for better material.

MANCOS SHALE.

The formation next above the Dakota is the Mancos shale, a thick mass of homogeneous clay shale with a few more sandy layers. It is considered here as a single unit, although it has formerly been subdivided into various formations, largely on paleontologic grounds. The relation of the Mancos shale to the subdivisions of the earlier explorers is indicated in the correlation table on page 27. From this it may be seen that Mancos includes all that has been previously termed Colorado and also a part of that classed as Fox Hills by White, of the Hayden Survey. It thus includes also the Benton, Niobrara, and a part of the Pierre formations, according to a classification of the Cretaceous section based on subdivisions originally

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adopted for strata of the upper Missouri River and adjoining fields. In brief, the Mancos is intended to include all of the predominatingly shaly strata above the Dakota and below the massive sandstones of the next succeeding or Mesaverde formation.

Raven Park is eroded on the Mancos shale, and it is in this formation that the oil of the Rangely field has been found. The least-altered exposures of these beds known in this area are those found in the bluffs along the north side of White River. Here the shale occurs in slightly weathered condition and presents a more compact, slaty appearance than is usual for this formation. Where fresh and undisturbed the shale is dark and fine grained, and in part at least shows thin lamination with considerable cross jointing. As more commonly exposed in escarpment bluffs or in wash banks of the many intermittent drainage channels, it dries to a lighter-gray color, blending with that of the soil into which it so readily breaks down. By reason of its nonresistant nature this formation commonly gives way to a heavy clay soil cover over low, rounded slopes, and is rarely exposed in a fresh condition.

The basal part of the Mancos shale may be naturally and readily distinguished as a distinct division of the formation, and contains Benton fossils. The Dakota sandstone is almost invariably overlain immediately by 200 feet or more of dense black slaty shale, which usually forms a long, low valley on the dip-slope side of the Dakota ridge. Above these beds is a similar thickness of shaly strata containing a number of more resistant beds of sandstone and limestone, which usually give rise to a distinct line of minor hogbacks similar to those of the Dakota, though of lesser elevation and more largely composed of shaly strata. The sandy layers are in many places of dark color and of moderately fine and even grain, and are as a rule flaggy or somewhat thinly bedded. These beds are commonly fossiliferous, and the calcareous beds also contain abundant shells. Collections obtained from many localities assign these rocks definitely to the upper part of the Benton shale.[a] The following is a list of identified species from the Willow Creek section described above:

Benton fossils from Willow Creek at the southern foot of Blue Mountain.

Ostrea lugubris Conrad.
Inoceramus fragilis H. and M.
Inoceramus dimidius White.
Scaphites warreni M. and H.
Prionocyclus sp.

[a] Determinations by Dr. T. W. Stanton; collections now in United States National Museum.

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Above the sandstones the remainder of this great shale formation attains a thickness of approximately 5,000 feet, or about 1 mile. It is to all appearances of homogeneous composition throughout, but the records of oil wells driven through it distinguish layers described by some of the drillers as sandy.

The uppermost part of the Mancos shale is perhaps more commonly exhibited at outcrops than any other part of the formation, with the exception of the lowest few hundred feet already described. By reason of the protection offered by the lowest sandstone layers of the next succeeding formation, it occupies in many places nearly the whole face of the escarpment up to heights of 600 or 800 feet. Of these topmost beds the lower portion is normally buried in the débris that slides down from the steep slopes above. The shale here appears to be lighter in color and more sandy than the basal beds already described, but it is uncertain whether this is the result of long exposure to weather and the consequent drying out of its natural moisture, or to variation of constitution in the upper part of the formation.

The soil that forms upon the surface of the Mancos shale is a compact clay, very hard when dry but becoming a deep plastic mud when thoroughly wet. This soil is usually hard and dry during the summer, when its surface becomes deeply cracked and fissured. Rains of short duration, such as frequently occur in the summer season, scarcely penetrate the soil at all, except as they fill these cracks. Surface water runs off rapidly, cutting abrupt vertical-sided channels or miniature canyons even to a depth of 50 feet or more. These gullies rapidly extend and deepen with each succeeding flood, and in places the dissection becomes so intricate as to produce a typical badland. Areas of such topography, which characterizes much of Raven Park, are accessible only with much difficulty, and then only by avoiding the stream courses as far as possible and following the dividing ridges.

The soil is in many places filled or covered with scattered fragments of selenite, which is gypsum in its clear, crystalline form, and larger pieces of this mineral are strewn about upon the surface, as if residual in the soil from the disintegration and removal of the original shale.

The fossils that have been found in the Mancos shale were obtained mainly near the base (see list of Benton fossils, p. 15) and from the upper layers near the base of the next succeeding formation. The fossils from these upper layers are of marine types, which were formerly considered as characteristic of a so-called Fox Hills fauna, and the beds were included by White in his formation of that name. The

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following is a list of species obtained during the work of the last season from localities in and adjacent to Raven Park:

Fossils from upper part of Mancos shale in White River valley.[a]

Serpula sp.	Legumen sp.
Ostrea sp.	Leptosolen sp.
Syncyclonema rigida H. and M.	Anatina sp.
Avicula nebrascana E. and S.	Goniomya americana M. and H.
Inoceramus sagensis Owen.	Liopistha undata M. and H.
Inoceramus cripsi var. barabini Morton.	Pholadomya sp.
	Spironema? sp.
Mytilus subarcuatus M. and H.	Odontobasis sp.
Sphæriola? cordata M. and H.	Cinulia sp.
Cardium speciosum M. and H.	Anisomyon sp.
Lucina sp.	Baculites compressus Say.

The thickness of the Mancos shale is a fundamental consideration in determining the depth to which wells must be sunk in the Rangely field in order to reach the Dakota sandstone. As a large part of the drilling has been carried on with this specific purpose in view the question of that thickness has received much attention from the drillers. When prospecting in the field was first started, White's estimates, given in the Hayden report, were accepted apparently without question. White gave the thickness of the "Colorado" formation as 2,000 feet in the upper White River valley, near Agency Park, but also stated that it was much thinner toward the west, in the vicinity of Raven Park. The first drilling in the Rangely field, however, showed that the figures given in that report were too small. Various attempts were then made to get more accurate information on this subject, but most of them were not very successful. For this reason the thickness of the formation is fully discussed here, and the evidence on which the conclusions are based is given in considerable detail.

The thickness of the Mancos shale may be determined from its upturned edge exposed along the southern foot of Blue Mountain, where these beds form a long, low valley parallel to and south of the Dakota ridge. Several estimates of this thickness have been made in recent years by those interested in drilling through the formation in the Rangely oil field. Most of such estimates have been made just east of the Willow Creek locality at which the detailed section of the Dakota formation (p. 13) was obtained. Chain measurements by Mr. C. F. Carney and others, of Meeker, are said to have shown the breadth of the Mancos Valley at this point to be 4,750 feet. The central portion of the valley is buried in alluvium; consequently the only

[a] Determinations by Dr. T. W. Stanton; collections now in United States National Museum.

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dip measurements available on which to base an estimate of the true thickness of the shale are those shown in the rocky ridges along the valley margins at the north and south. These dips on the two sides of the valley do not accord, ranging from 33° to about 45° on the north, along the Dakota ridge, and increasing to angles of 75° and near verticality along the southern margin. Considerable uncertainty remains in the estimates of stratigraphic thicknesses based on the data given above, for if the beds are nearly vertical across the major portion of the valley, as they are at its southern margin, their thickness would be from 4,500 to 4,700 feet, but if the lighter dips at the north continue across the valley the thickness of strata represented is only about 3,000 feet. It may be concluded that the true thickness is somewhere between these two limits. The writer is inclined to believe, however, that no measurement obtained in this locality is reliable, and that the apparent regularity of the structure is misleading. As may be seen by reference to the geologic map (Pl. II) accompanying this report, the Dakota hogback bends rather abruptly at the point where Willow Creek emerges from it, about 800 feet east of the center of sec. 12, T. 3 N., R. 103 W. A general view of the topography in this vicinity clearly reveals also a corresponding bend in the structure of all the formations exposed. Thus the longitudinal valley which is eroded along the outcrop of the Mancos shale immediately south of and parallel to Blue Mountain bends abruptly across a zone which extends about due south from the site of the Willow Creek section. At the southern margin of the valley directly opposite the Willow Creek section (NE. ¼ SE. ¼ sec. 13, T. 3 N., R. 103 W.) the strata are irregular and apparently broken and this disturbance continues to the northeast for at least a quarter of a mile, the valley narrowing markedly in that direction. It is in this constricted portion of the valley that most of the measurements of the thickness of the Mancos shale have been made. The disturbance in this area is thought to have been produced by shearing movements within the mass of the shale, rather than by clearly defined faults. The irregular structure is evidently related to the narrowing or partial discontinuity of the Red Wash syncline, which extends eastward, broadening and deepening from this point, as is explained in the section on structure.

There are many places in the valley south of Blue Mountain where it seems fair to assume a uniform dip clear across the valley, but in most of these localities the greater part of each section is concealed beneath the valley wash. Calculations made from measurements at several such points indicate a minimum thickness of about 5,000 feet for the Mancos shale.

An estimate of the thickness of the Mancos shale can doubtless be obtained from well records, if the wells ever reach the Dakota in

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localities where an estimate of that part of the shale which has been eroded from the well site can also be obtained. The Union well in Raven Park, described on page 42, has been sunk to a depth of 3,655 feet in lightly dipping strata, so that this figure very closely approximates the true thickness of the beds passed through. About 1,200 feet of strata have been eroded from the site on which the well is located, this estimate being based on the same data which were used in constructing the cross section (Pl. III, section C-D) that passes through and includes the Union well. There is some evidence that the bottom of this well is about 300 feet above the Dakota sandstone. The total thickness thus obtained is slightly greater than 5,000 feet when corrected for the light dip of the strata, and this agrees very closely with the estimates made at the more favorable localities along Blue Mountain.

MESAVERDE FORMATION.

The uppermost and youngest strata of the Upper Cretaceous section in the Rangely district, as well as in the whole of the Grand River basin, are equivalent in age to the Mesaverde formation as mapped in the Yampa coal field.[a] These beds succeed and overlie the Mancos shale, from which they are distinguished chiefly by their generally more sandy character and the prominence of the massive sandstone ledges. As a whole this formation is composed of massive sandstones, interbedded with sandy shales and many beds of coal and carbonaceous shale. Of these rocks the sandstones are most conspicuous by reason of their greater resistance to erosion than that offered by the softer beds. The formation is thus typically represented by a more or less rugged country, characterized by escarpment ledges and cliffs. The massive sandstones are commonly of medium or rather coarse grained texture, locally showing some cross-bedding, although this is not a distinguishing feature. In many places they weather near the surface to a variety of shades, usually of reddish or yellowish color, which is probably the result of the oxidation of some iron constituents. Where these beds are exposed in mines or in freshly cut rock faces, they are commonly of clear white sand, firmly cemented when fresh, but they crumble and soften readily with exposure to the weather. Much of the cementing material in the sandstone is probably of calcareous or alkaline nature, as calcareous, magnesian, and ferruginous salts are almost invariably found in the waters that leach from these beds. Such salts commonly occur as efflorescent deposits in natural cavities in the massive sandstone, or under projecting ledges where sheltered from the solvent action of rain and snow water.

[a] Fenneman, N. M., and Gale, H. S., The Yampa coal field, Routt County, Colo.: Bull. U. S. Geol. Survey No. 297, 1906, pp. 22–28.

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In general the shales differ from those which constitute the main body of the Mancos, being usually of lighter color as well as more sandy. They show much variation in constitution, ranging from compact clay shale somewhat resembling the typical Mancos rock to sandy shale and from this to thin-bedded and flaggy sandstone. The coal beds constitute one of the most important economic resources of the region. The coals are bituminous and of a good grade, being similar to those of the Danforth Hills field, such as the coals near Meeker. As they are elsewhere[a] described in considerable detail, further discussion of them is omitted here.

As shown on the geologic map forming Pl. II (pocket), the lower part of the Mesaverde is distinguished as a separate member by a distinct pattern, the top boundary representing the base of the principal groups of workable coals. Within a small area such as the Rangely district certain parts of the Mesaverde formation are sufficiently continuous and characteristic to be distinguished and traced throughout the field, although they vary greatly in actual detail within very short distances. Perhaps the most conspicuously constant member of the whole formation as viewed from Raven Park is the irregularly oval escarpment surrounding the valley. This escarpment is composed of the lowest sandstone member of the formation, and is locally known as the "rim rock." The view given in Pl. IV, A, illustrates a characteristic portion of this member, and shows the underlying bluff of Mancos shale, capped and preserved by the hard sandstone ledge. The sandstone, or "rim rock" itself, is a bed ranging in general from 20 to 50 feet in thickness. Above this is a mass of characteristic sandy shale, 500 to 600 feet thick. These shales are, in general, easily eroded, leaving the outer edge and in many places a considerable portion of the back slope of the "rim rock" bare. Beyond the gentle back slope of the "rim rock" (as expressed in the contouring on the topographic map) a second characteristic escarpment rises above the first, capped likewise by a group of cliff-forming sandstone beds. Of these the lowest is most commonly of a rusty-brown color, resembling the weathered ledge of the "rim rock" below, and the third and fourth as commonly show a clear white aspect, in marked contrast to the group of darker ledges below. At about the horizon of the third sandstone above the base a thin bed of coal or dark carbonaceous shale is present at many places. This section is significant for purposes of correlation by comparison with the strikingly similar section near the base of the same part of the formation in Agency Park, north of Meeker, and also at many localities along the borders of Axial Basin. Above this

[a] Progress report on investigation of coal fields in northwestern Colorado and northeastern Utah: Bull. U. S. Geol. Survey No. 341, 1908.

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second group of sandstones the members become less distinct as individuals, but merge into a prominent series of cliff-forming sandstones, continuing as such up to the horizon of the principal coal group already mentioned. Into these massive sandstones the steep rocky gorges and canyons of many intersecting streams are cut. This lower part of the formation is relatively barren of coal, but is prominent as a ridge maker. Its total thickness ranges from 1,000 to 1,500 feet. The measurements from which the larger estimate is obtained were made in Chase Gulch, northeast of Rangely.

The upper part of the Mesaverde formation is also distinguished as a separate member on the geologic map, the line which marks the lower limit of the principal group of workable coals representing its base. These upper strata resemble very closely the underlying beds, except that the predominance of the massive and resistant sandstone members is not so pronounced and the resulting topography is consequently not so rugged. One of the most readily distinguished horizons in the Mesaverde is the bottom of the principal workable coals. This general horizon has been traced continuously for at least 200 miles along the outcrop and, as already mentioned, is shown by a line on Pl. II. It is marked by a conspicuous white sandstone bed which is commonly one of the most massive members of the whole formation. In a large part of the Danforth Hills this bed is a very prominent white ledge. From its characteristic appearance it has come to be known in the vicinity of Axial post-office as the "white rock." As this member is traced west of that field it disappears and reappears intermittently, so that its position is locally a matter of some conjecture, even in a well-exposed section. Here, as in the Danforth Hills, wherever it can be recognized it furnishes a key rock by which to identify the more valuable coal beds that lie above it.

Above the "white rock" the sandstones and shales alternate in a variable succession, showing almost everywhere some signs of the coal beds that they include. The coals themselves are in many places made conspicuous by the burning which has taken place along their outcrops, baking the inclosing strata to brilliant shades of red and yellow and hardening the clay and shale to a flinty texture. Less commonly the coal beds are found in natural outcrop or show as black streaks along the hillside. By reason of the weaker character of this carbonaceous material it is usually broken down and concealed by the débris of the harder adjacent strata. From the "white rock" to the top of the formation, coals occur at irregular intervals, the principal beds being almost invariably concentrated near the base, or not far above the "white rock."

A number of carefully measured sections of the Mesaverde formation, taken along the Grand Hogback east of the Rangely district,

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have already been published in a description of the upper White River coal fields.[a] In that region the formation attains a thickness of somewhat over 5,000 feet, or approximately 1 mile. Opportunities for measurement near Raven Park are not so favorable, but the thickness of the Mesaverde here appears to be not more than half that which prevails in the Grand Hogback and Danforth Hills. The principal difficulty in obtaining a satisfactory measurement in the lower White River territory lies in the uncertainty regarding the upper limit of the formation. It is possible that during Mesaverde time a smaller amount of sediment was deposited in the Raven Park region than in the Danforth Hills and farther south. On the other hand, the greater thickness of the formation in the eastern part of the basin is probably to be explained by the assumption that most of the beds originally deposited there still remain, whereas in the western part a large amount had probably been eroded from the upper portion of the formation before the next succeeding strata were laid down. This explanation is more probable, because the section of the Mesaverde formation near Raven Park corresponds in grouping as well as in thicknesses to the lower part of the thicker section farther east. It may be noted from a study of the sections of the Mesaverde near the Grand Hogback and in the Danforth Hills that the principal group of workable coal beds is in the lower part of that formation, immediately overlying a relatively barren zone of 1,000 feet or more. This coal-bearing group is in turn overlain by a considerable thickness of strata containing scattered coal beds or carbonaceous streaks, some of which are of workable thickness. Additional evidence of the removal by erosion of the upper beds in the western part of the field is found in the fact that as these rocks are traced northwestward into Utah they apparently show progressively deeper erosion, without any notable change in the character or grouping of the basal members. The Mesaverde formation may be followed continuously to and beyond Green River, where its outcrop crosses that stream just below the mouth of Ashley Creek in Utah. At this place all of the workable coal group is wanting except one or two coal beds, and these occur at the top of the section, which is roughly estimated as not more than 1,500 feet in thickness.

Not only has a great amount of the Mesaverde formation been eroded from the western part of the White River region, but other and higher Cretaceous formations have probably also been removed from that entire basin, as they are present in adjacent fields to the north and east. In the Yampa coal field the Lewis shale and the Laramie formation overlie the Mesaverde, separating that formation

[a] Coal fields of the Danforth Hills and Grand Hogback in northwestern Colorado; Bull. U. S. Geol. Survey No. 316, 1907, p. 266.

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from the succeeding Tertiary sediments, which are similar to those that rest directly upon the Mesaverde in the Rangely field. It is therefore presumed either that beds corresponding to those now found in the Yampa field had been eroded from the Rangely district and vicinity before the deposition of the Tertiary beds began, or that the uppermost Cretaceous beds were never deposited in the Rangely district. In the latter case, the time during which these later beds were being laid down in other regions was marked by dry-land conditions in this district.

The stratigraphic horizon marking the disappearance of beds which are thought to have once been deposited and later eroded before succeeding deposits were laid down represents an interval in the geologic history of the earth probably as important as the time represented by many of the formations that still remain and may be studied at the present day. The causes that brought about first the deposition of certain beds and later the removal of the same material by erosion indicate changes in the earth's crust similar or related to the earth movements that produced the mountain ranges. Although the record of those events, to be interpreted from a study of the strata, may have been wholly or in part obliterated at certain localities, many of the missing clues may be obtained from other places. The horizon of a former land surface that was uplifted and subjected to erosion and subsequently submerged and subjected to renewed sedimentation is known as an erosional unconformity.

The tilted rocks exposed in the ridge north of and approximately parallel to White River between the mouths of Wolf and Red Wash creeks offer what is perhaps the best opportunity for measurements of the Mesaverde formation near the field. An estimate based on a measured line just east of Red Wash Creek (between secs. 13 and 18, 24 and 19, along the township line separating T. 3 N., R. 101 W., and T. 3 N., R. 100 W.) gives a total of only 2,500 feet. The upper limit of the section is defined by an exposure of the varicolored marl characteristic of the overlying Tertiary just east of this line, along the axis of the Red Wash syncline. Some fossils found immediately along the line of this cross section (100 paces southeast of the northeast corner of sec. 36, T. 3 N., R. 101 W., in a conglomerate ledge) also serve to indicate that the top of the formation had been reached and that as complete a section of the Mesaverde as now remains in this part of the field occurs at this place. These fossils consist of internal casts of a species of *Unio* and some indeterminable fragments of leaves. Doctor Stanton considers the *Unio* to be of an age later than the Mesaverde, possibly belonging to Fort Union or related time. He is also of the opinion that it is older than species previously known to have come from the Wasatch formation. No

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intermediate formation has been recognized in the Rangely field and these rocks are therefore included with the Wasatch formation.

The canyon of White River below Raven Park would seem at first sight to present a most excellent opportunity for obtaining a measurement of the thickness of the Mesaverde formation. Two factors, however, interfere with such a measurement at this locality. The first, which will be described in a subsequent paragraph, is the probable existence of a fault near the mouth of the canyon, and the second is a sharp divergence of dips and strikes along the river banks, caused by irregularity in geologic structure.

As has been explained, the precise determination of the upper limit of the Mesaverde is an especially perplexing problem in and about Raven Park. Near Meeker and along the Grand Hogback between White River and Grand River a bed of coarse bowlder and pebble conglomerate or "pudding stone" with a coarse white-sand matrix marks the boundary between characteristic Mesaverde beds below and the variegated marl and sandstone of the overlying Tertiary. In the Rangely district, however, no such clearly defined stratum was discovered, although some beds of conglomerate not closely resembling the Grand Hogback bed were found. These beds appear to be at or near the top of the Mesaverde formation, but in many places they could not be discovered and the sandstones of the Mesaverde could not be distinguished from those of the overlying beds. Consequently the exact upper limit of the formation could not in all places be determined. In some parts of the Rangely district the variegated colors of the overlying Tertiary beds are less conspicuous, although they are generally recognizable and serve as almost the only distinguishing mark of the transition to Tertiary strata. The occurrence at this horizon of some species of unios and one or more gasteropods, including one which is probably a *Goniobasis*, was not considered determinative, but is thought to indicate the Tertiary age of the beds including them and is considered as a useful clue in the mapping of the Cretaceous-Tertiary boundary at the top of the Mesaverde.

Fossils have been found in all parts of the Mesaverde formation. These indicate that the basal beds are mostly of marine origin, up to and probably including the "white rock." This basal portion of the formation is distinguished as a separate member on the geologic map (Pl. II). Above the "white rock" fresh- and brackish-water invertebrates and plants indicate a change in the body of water in which these beds were formed. The fresh- or brackish-water conditions were not permanent, however, and gave way to true marine conditions when the beds near the top of the formation were deposited. Fresh-water fossils are also found in the lower predominatingly marine beds. The following is a list of the fossils collected from the Mesaverde

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formation in this field or along the drainage basins of White and Yampa rivers:

Fossils obtained from Mesaverde formation in White River districts.

INVERTEBRATES.[a]

Ostrea subtrigonalis E. and S.	Corbicula occidentalis M. and H.
Ostrea glabra var. arcuatilis Meek.	Cardium speciosum M. and H.
Anomia micronema Meek.	Legumen sp.
Modiola laticostata (White).	Donax? sp.
Inoceramus sagensis Owen.	Mactra formosa M. and H.
Inoceramus cripsi var. barabini Morton.	Corbula undifera Meek.
	Viviparus sp.
Inoceramus erectus Meek.	Tulotoma thompsoni White.
Unio sp. cf. U. brachyopisthus White.	Campeloma? sp.
Unio cf. danæ M. and H.	Goniobasis? sp.
Corbicula cytheriformis M. and H.	Baculites compressus Say.

PLANTS.[b]

Halymenites.	Dammara cf. D. acicularis Knowlton.
Cunninghamites elegans? (Corda) Endl.	Corylus cf. C. Macquarrii (Forbes) Heer.
Ficus speciossissima Ward.	
Ficus squarrosa? Knowlton.	Magnolia tenuinervis Lesq.
Ficus sp.?	Zizyphus sp.?
Ficus planicostata Lesq.	Celastrus sp.
Sapindus sp.	Platanus sp.
Sequoia Reichenbachi (Gein.) Heer.	Geinitzia sp.

TERTIARY FORMATIONS.

Between the top of the Mesaverde formation and the base of the overlying Tertiary strata an unconformity exists in the Rangely district, as has already been stated. Much difficulty has been experienced in determining precisely the horizon at which this unconformity occurs, as no change in the bedding of the strata has been noted. Definition of the top of the Mesaverde as well as the base of the Tertiary depends on this feature. Both formations contain alternating beds of massive sandstone and sandy shale which are so similar that in many places they can not be distinguished one from another. The chief characteristics of the lower Tertiary beds are the clays or marls of brilliant and variegated colors, which constitute in some places a mass 2,000 feet to possibly 4,000 feet in thickness. The variegated strata are supposed to be of Wasatch age and were so mapped in the Hayden reports. Fossils obtained from the basal part of this formation have been identified as characteristic of the Fort Union formation. The Wasatch is quite distinct as a lithologic unit along the western flank of the Grand Hogback and the Danforth Hills, where

[a] Determined by T. W. Stanton. [b] Determined by F. H. Knowlton.

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it attains a thickness of at least 4,000 feet. In the vicinity of Raven Park, however, these colored clays are much less conspicuous. Below the Cathedral Bluffs red patches are exposed only here and there, and the massive white sandstones very closely resemble those of the Mesaverde formation below.

Overlying the Wasatch or lowest Tertiary formation is a second mass of shale and sandstone without the variegated colors. These rocks have been named Green River group in the earlier geologic work. They are characteristically exposed in escarpments of considerable elevation, among the best examples being those of the Book Cliffs and Cathedral Bluffs, south of Raven Park. These steep scarps stand at elevations of 1,500 to 2,000 feet above the neighboring valleys, and are almost everywhere characterized by the chalky-white appearance of the weathered cliffs as seen at a distance. The Green River formation usually lies nearly horizontal or with a very light dip, and in most places it forms a high mesa or plateau surface, occupying the undisturbed interiors of the great structural basins.

In detail the Green River formation is composed of sandstones and thin-bedded slaty shales, with layers of limestone and calcareous shale. Many beds of oolitic or pisolitic limestone occur, and at some localities they form the major part of the harder beds which the formation contains. In many places the thin-bedded shale is of dark or brownish color when freshly exposed, in marked contrast to the almost universal whitish aspect of nearly all these beds on their weathered edges. The characteristic occurrence of most of these Tertiary beds in areas of slight structural disturbance and their consequent horizontal position are discussed in the section on structure (p. 34).

MODIFICATION OF FORMER CRETACEOUS CLASSIFICATIONS IN THE PRESENT PAPER.

All the names of Cretaceous formations used in the reports of the Hayden, King, and Powell surveys, with the single exception of Dakota sandstone, have been superseded by other names in the foregoing descriptions. The relations of this recently adopted nomenclature to the old classifications and also the relations of those formations to each other are indicated in the accompanying table of correlations. The classification of the Cretaceous strata above the Dakota as Laramie, Lewis, Mesaverde, and Mancos here replaces altogether the older grouping of Laramie, Fox Hills, and Colorado as used by the King and Hayden surveys for this general region. Although the term Laramie is retained in the present classification as the name of the uppermost of the formations of Cretaceous age as they are now recognized, this term is no longer accepted as it was formerly applied by any of the early investigators in this

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Table of correlations to explain the relations of the various groupings adopted for western Colorado strata.

[The horizontal arrangement is intended to indicate actual equivalency of the strata. The heavy lines indicate the various conclusions as to the age of the strata thus designated.]

	Hayden, about 1870.	King, Fortieth Parallel Survey, 1875.	Powell, Geology of Uinta Mountains, 1876.	White, Hayden Survey, 1878; Ninth Ann. Rept. U. S. Geol. Survey, 1889.	Cross, San Juan folios, U. S. Geol. Survey, 1899.	Fenneman and Gale, Yampa coal field report, Bull. U. S. Geol. Survey No. 297, 1907.	Present report.	
Tertiary.	Green River.	Uinta. / Green River.	Green River.	Green River.			Green River.	Tertiary.
	Wasatch.	Vermilion Creek. (a)	Various formations mapped as Bitter Creek.	Wasatch.			Wasatch.	
	All coal-bearing formations mapped as Lignitic.			Neither unconformity nor hiatus recognized.			Fort Union? (a)	
					Laramie.	Laramie.	Laramie.	Cretaceous.
					Lewis.	Lewis.	Lewis.	
		Laramie.	(b) Point of Rocks.	Laramie. [c]	Mesaverde.	Mesaverde.	Mesaverde.	
Cretaceous.	Fox Hills.	Fox Hills.	Salt Wells.	Fox Hills.				
	Pierre. Niobrara. Benton.	Colorado.	Sulphur Creek.	Colorado.	Mancos.	Mancos.	Mancos.	
	Dakota.	Dakota.	Henrys Fork.	Dakota.	Dakota.	Dakota.	Dakota.	
Jura-Trias.	Jurassic.		Flaming Gorge.	Jurassic.	Gunnison. McElmo.		"Flaming Gorge."	Jurassic.
			White Cliff.		La Plata.		"White Cliff."	
	Triassic.			Triassic.				

[a] Unconformity. [b] Local unconformity. [c] White regarded this Laramie as transitional between the Cretaceous and Tertiary.

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particular field—a point that is discussed in detail farther on (see pp. 27–32). This more recently adopted nomenclature has already been introduced into the literature of northwestern Colorado geology.[a] Still more recent stratigraphic studies have confirmed the tentative conclusions of the Yampa coal report, relating to the necessity for a revised nomenclature, and also the expediency of the names there adopted for the northwestern Colorado region.

Although the classifications and conclusions of the early geologic writers on this field have gained wide recognition and become very firmly established in a popular as well as more technical way, there is ample justification and indeed urgent necessity for abandoning entirely this older terminology and revising the basis of its stratigraphic grouping. This revision, as adopted here, is intended to accomplish three specific aims. These are, first, to do away with the uncertainty that prevails with regard to the precise definitions and limits assigned to certain terms by the various authors in the older work, the differing significance attached to the geologic term Colorado being the principal instance; second, to establish a stratigraphic and lithologic basis of separation of the formations instead of the previously adopted paleontologic basis, which depended on distinctions that are always difficult and locally impossible to recognize; third, to call attention to and correct an old and now widespread misinterpretation of the age of the beds formerly called "Laramie" in this field—a group of strata that should never have been included in the formations to which that name was applied, even according to the original somewhat uncertain definition of the term. These points are considered in more detail as follows:

First. The use of the same geologic formation name with varying significance is found in the application made of the term Colorado by the King and Hayden surveys. This disagreement is indicated in the correlation table (p. 27). In the reports of the Fortieth Parallel Survey the term Colorado is defined so as to include a considerably wider stratigraphic range than as it was later used by White in his work with the Hayden Survey. The reasons for this confusion are largely paleontologic, as stated by White in his report.[b] He says:

> While adopting the name "Colorado group" of Mr. King, I, for paleontological reasons chiefly, so restrict its application as to include only what I understand to be equivalent with Nos. 2 and 3 of Meek and Hayden's original section, leaving the equivalent of No. 4 to be included with the strata of the Fox Hills group, instead of with the Colorado group, as Mr. King has done.

The restriction of the Colorado was not successfully applied in the mapping of the Rangely district, where this subdivision could not be

[a] The Yampa coal field, Routt County, Colo.: Bull. U. S. Geol. Survey No. 297, 1907.
[b] Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1878, pp. 20–21, 30.

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traced on a lithologic basis. White's usage of the term has, however, been generally and consistently followed in other fields for thirty years and it is still of great value as a correlation term. As Stanton states, the group is a natural division from a lithologic as well as a paleontologic standpoint east of the Rocky Mountains, where the calcareous Niobrara separates the two dark shales, Benton below and Pierre above.

Second. The necessity for the use of stratigraphic and lithologic distinctions as the primary basis in geologic mapping is well brought out by the difficulties that have been encountered in Raven Park and adjoining districts. White himself admits[a] that "all the groups of strata that are referred to the Cretaceous period in this report are, within this district, not only strictly conformable with each other as regards their stratification, but I have never been able to fix upon a plane of demarkation between any of them with entire precision." White's grouping of the strata was made on a purely paleontologic basis, a policy which he considered imperatively necessary[b] for the purpose of establishing at once wide-range correlations over extensive areas. Thus the division planes which he adopted depended entirely on scattering and to a large extent inadequate fossil evidence and not on recognizable changes in the rock strata themselves. His planes of demarkation were thus impossible of precise definition and could never or very rarely be identified exactly in the field. The geologic boundaries he has shown on his maps are therefore scarcely more than mere estimates or are purely arbitrary lines which had to be assumed in the absence of the criteria necessary to establish any actual subdivision. Even if sufficient fossil evidence were everywhere at hand to make such a division it is extremely doubtful if it would serve the most useful purposes, as no one without paleontologic training could appreciate its value when drawn.

Although it now appears to be more practical to map geologic formations in any particular field largely on the basis of lithologic distinctions—that is, changes in the character of the rock strata themselves—no one will question the necessity of paleontologic evidence in determining the position of these rocks in the geologic time scale and their correlation across the larger areas or in discontinuous fields. The errors introduced by some of the older surveys as a result of attempted correlation on the basis of lithologic similarity of rock formations occurring in discontinuous areas have been as many and as serious as those resulting from the use of paleontologic criteria. The argument of the present work is that the more practical method of subdivision should be applied to any specific stratigraphic section. For any one field or basin marked changes in the

[a] Op. cit., p. 29.

[b] Op. cit., p. 30, line 30.

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constitution of the rock strata themselves furnish as important evidence of changes in geography and in conditions of sedimentation during past geologic time as do the fragmentary records of animal life that now happen to be preserved.

A part of the confusion in the early geologic mapping based on paleontologic distinctions was probably due to the failure at that time to understand the significance of the so-called Fox Hills fauna. It is likely that the use of the term Fox Hills to define any particular formation representing a specific time interval in the Cretaceous history of the Rocky Mountain region will now be abandoned. This conclusion has been reached by Stanton and others after an extensive study of western Cretaceous stratigraphy, and so far as known to the author is not now disputed by anyone familiar with these problems. As stated by Stanton,[a] "Faunas similar to that of the Fox Hills sandstone have a great vertical range and are likely to be found at any horizon within the Montana group where a littoral or shallow-water facies is developed. The use of the term Fox Hills as a formation or horizon name outside of the original area in South Dakota is therefore of doubtful propriety, as experience has shown."

In most of the fields west of the Rocky Mountains or the Great Plains the term Pierre has also led to some confusion. Sections in central and northern Montana that have been described have defined as the Pierre formation (later named Bearpaw, although still assigned to Pierre age) a shale body overlying the Judith River, Claggett, and Eagle formations. The latter three formations are now considered to be in greater part the equivalents of the Mesaverde formation of northwestern Colorado and southern Wyoming sections. In the Colorado and Wyoming fields, however, Pierre has been used to denote beds which normally underlie the Mesaverde formation. The shales above and below the Mesaverde are of similar lithologic composition, resembling the Pierre shale of the Great Plains region, and also contain fossils that are commonly found in the Pierre of the Great Plains. Pierre is certainly a valid and useful term in the large area where the Niobrara is typically developed and Mesaverde and similar formations do not exist, but probably has no place in a section which also includes either the Mesaverde or the Judith River.

Third: With regard to the previous misinterpretation of the term Laramie so far as it relates to the Raven Park district the solution is clear. None of the rocks in this field to which the name Laramie has hitherto been applied are properly so classed. The Laramie formation in the sense in which the name was originally adopted is almost certainly not represented at all by any of the strata exposed in the immediate vicinity of Raven Park. Either this formation was never

[a] Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River beds: Bull. U. S. Geol. Survey No. 257, 1905, p. 66.

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deposited in this field or if it was deposited it was completely eroded at a later time, before the overlying Tertiary beds were laid down.

The name Laramie was adopted by agreement between King and Hayden to apply to the Cretaceous strata then thought to lie at the top of that system, conformably above the marine deposits. It was assumed at that time that marine conditions existed throughout a large part of the interior province during most of Cretaceous time, and that these conditions terminated with a succession of crustal movements that uplifted the Rocky and Uinta mountain ranges. Portions of this sea were supposed to have been cut off in interior basins at the time of that upheaval, so that their waters gradually became less and less salty, until the fresh-water conditions which marked Tertiary time were fully established. It was clearly the intention of the early investigators to denote the beds laid down during this transitional stage by a formation name, for which purpose Laramie was agreed upon. In terms of later geologic nomenclature, therefore, Laramie was probably meant to include all the brackish-water deposits which succeeded the Montana, or latest marine sediments then recognized in the Cretaceous system. This formation was less certainly defined by an upper limit, but was in all probability intended to include all strata up to whatever beds should be considered as belonging to the fresh-water or Tertiary basins established after the mountain-building movements already mentioned were completed.

Early investigators did not at first recognize that temporary transitions to brackish and fresh water deposition occurred at various periods during marine Cretaceous time. Such conditions apparently prevailed for a while in certain interior basins at the same time that the normal marine deposits were being laid down in adjoining regions. These periods which preceded the close of the Cretaceous were, however, of short duration and were apparently terminated by incursions of the sea and reestablishment of salt-water conditions. The Judith River beds of Montana and the Mesaverde formation of Colorado are examples of deposits laid down during such periods. Both contain a fauna and flora resembling those of the Laramie and were formerly supposed to be Laramie. Both are now known, however, to represent stages of fresh-water deposition somewhat similar to those which prevailed during Laramie time, but occurring long before the close of the Cretaceous. It is perfectly clear that such beds can not be included under any interpretation which can be reasonably given to the original definition and agreement as to the use of the term Laramie.

The fact that Mesaverde time was succeeded by a considerable period of true marine deposition was entirely unrecognized at the time of the earlier surveys. Evidence of this return of salt-water conditions is found in the existence of a normal succession of marine

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strata overlying the Mesaverde formation in the Yampa River valley, north of the fields structurally included with those of the White River districts. The Yampa basin contains a great body of dark clay shale with lenticular interbedded sandstones and calcareous layers, overlain by a second large body of sandstones, sandy shales, and coal beds. Of these deposits the lower or shale group (Lewis shale) is of marine origin and the overlying beds indicate a second transitory stage, reintroducing brackish and fresh-water conditions. The later beds are thought to represent, at least in part, the Laramie, so far as the best interpretation of that term is at present understood.

STRUCTURE.

GENERAL FEATURES.

The geologic structure of the region here discussed can best be described by means of graphic sections. Several of these have been constructed to represent the features exhibited in the Rangely district and are reproduced in Pl. III. The locations of the lines along which these cross sections are drawn are shown on the geologic map (Pl. II, pocket) by letters corresponding with those on the sections.

The whole field constitutes only a portion of the huge structural basin that lies south of the Uinta Mountains. The term basin is variously used, but in its structural geologic sense it refers to the attitude of the rock strata and is intended to signify a syncline or relatively depressed portion of the earth's crust, commonly retaining beds of the younger geologic formations, while the corresponding beds are very likely to have been worn away over the uplifted portions that surround and form the rim of the basin. A basin in this sense should not be confused with a topographic basin, which is also commonly understood as a relative depression, but referring to the earth's surface only without any implication as to the attitude of the underlying strata—for instance, a valley or drainage basin. Raven Park is an excellent example of a topographic basin, but is structurally quite the reverse of a basin, being formed of strata relatively uplifted at the center or axis, and not depressed.

The Raven Park district lies on the northern margin of the Uinta Basin, where the younger beds that occupy the major basin are upturned and eroded along the uplifted axes of the Uinta Mountain system. The Uinta Basin as a whole lies south of the Uinta Range in Utah and Colorado. It is limited on the east by the various axes of uplift which form the western foothills of the Rocky Mountain system. It extends westward to the Wasatch Mountains in Utah and southward to the uplifted areas of the Uncompahgre Plateau and the San Rafael Swell. In the major structural basin, as well as in the subordinate synclines included within it, the axes or deepest

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portions of the folds lie in the main parallel to the major axes of the uplifts that border them. Thus within the influence of the Rocky Mountain system all the folds exhibit marked parallelism in a northwest-southeast direction. The axes of the Uinta system trend more nearly east and west, and an extension of the Uinta uplift eastward as a comparatively simple anticline through Axial Basin bends southeastward and merges into the corresponding uplifts and folds of the White River Plateau, which are clearly a part of the Rocky Mountain system. This connecting anticline is comparatively inconspicuous as regards its magnitude of uplift, but it connects the two great mountain systems and separates two huge basins of the younger Cretaceous and Tertiary rocks which lie north and south of it. The basin to the north is described in part as the Washakie Basin in Wyoming, a portion of the greater structural feature known as the Green River Basin, and terminates southeastward in the valley of upper Yampa River in Colorado.

The Colorado portion of the Uinta Basin has been termed the Grand River Basin, and is in a minor way naturally distinct from the larger extension of the Uinta Basin into Utah, being separated by a series of anticlinal or domal uplifts of which the Raven Park fold is one. This series of uplifts has an approximately north-south axis. It is, however, composed of three or more distinct structural domes, to be presently described in detail, whose axes of greater elongation are approximately parallel to each other but oblique to their north-south alignment as a group. The longer axis of the Raven Park anticline lies apparently in extension of the major axis of the whole Grand River Basin. The similar and more pronounced fold of the southern Blue Mountain region lies north of the Raven Park anticline. A less pronounced fold south of the Raven Park anticline will be described as the Douglas Creek uplift. South of the Douglas Creek uplift and beyond the area here considered in detail the Uinta Basin as a whole terminates against the flexures bordering the Uncompahgre Plateau south of Grand River, just as it does against the Uinta axes on the north.

RAVEN PARK ANTICLINE.

The structure of Raven Park is essentially that of a simple anticline or dome of the underlying strata, the valley itself having been eroded from the crest of the uplifted portion. The strata are inclined outward, dipping in all directions from the center or axis of the uplift. The dome is roughly oval in form, the axis or longer diameter lying in an almost due northwest-southeast direction. At either end of the axis the fold flattens and is lost to view, merging

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into the flexures of adjoining areas. Toward the northwest flanks of the flexure unite, the strata becoming approximate zontal, with a number of minor irregularities, and the fold di entirely at a point near the Colorado-Utah State line. Beyo point all trace of subordinate folds is lost, the strata showin form southward dip away from the higher uplifts to the north tending in this way westward to the Green River Valley. S of Raven Park the fold apparently terminates in the flat-lyin ary beds of the high escarpment known as the Cathedral These strata fill most of the interior of the Grand River Basi portions that now remain are, as a rule, horizontal or only ver flexed or tilted, and constitute most of the high plateau surfa characterize that general region.

The Raven Park anticline is not a symmetrical fold. Tow northeast the strata dip away at light angles, averaging f to 6°, but the dips to the south and southwest are much st from 15° to about 35°—the flexure itself being very abrup characteristic of most of the folds in the western Cretaceous strata. These steeper dips are found along Raven Ridge a south side of White River.

As stated, the Raven Park anticline lies midway between flexures on the north and the south. All these folds exhibit s features of similarity and apparent relationship. The most nent of these features are the character and position of the f themselves, and the correspondence in direction of their longe It is of interest to note the gradation of the intensity of upli produced the various folds. In the Midland fold to the north t heaval was sufficient to bring to surface level rocks as old a boniferous, but even this uplift is of much less magnitude than s and greater folds immediately north of it. The Raven Par exposes the Mancos shale at its center. The Douglas Creek f is broader and of less intensity than that of Raven Park, so th upper portion is now largely capped by the Mesaverde strat younger than those found in Raven Park.

MIDLAND UPLIFT.

The Midland uplift was named and described by White[a] report of the Hayden Survey. The name is intended to includ anticlinal flexure that forms the southern margin of Blue Mou (Yampa Plateau of the earlier work), a portion of which was designated as the Midland Ridge. The southern part of this r of uplift is included in the area of the geologic map and sections accompany this report (Pls. II and III). It is in many respect

[a] Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1878, p.

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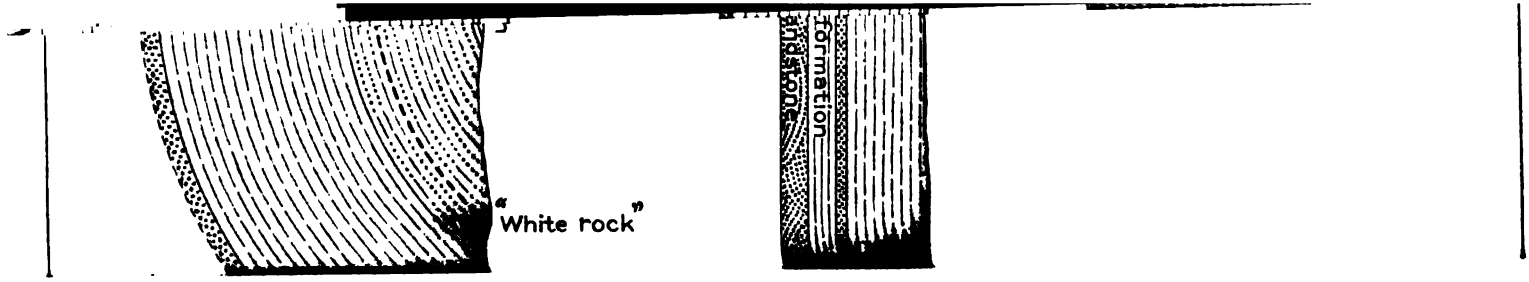

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most striking feature of the region and is of especial interest in connection with a study of the Raven Park uplift because of its similarity in form and parallelism of structure and the greater magnitude of the stratigraphic displacement which it represents. By reason of the greater intensity of its uplift, and also of later erosion along its axis, it brings to view a considerable section of the older strata which underlie Raven Park but are not there exposed.

Like the Raven Park anticline, the Midland uplift exposes at its center beds of weaker texture than those which compose the flanking ridges, and thus a portion of the axis or crest of the uplift is eroded to a valley of comparatively low relief. This valley is in form a great amphitheater about 15 miles in length, inclosed by an almost continuous wall of brilliantly colored strata. This escarpment is a striking feature of the landscape and can be seen from a great expanse of territory to the south as far as and beyond White River valley. It is in form a precipitous wall 1,000 to 1,500 feet in height, composed of brilliantly colored clay or shale capped by ledges of massive white sandstone. The underlying shale and sandstone present a banded appearance, a feature traceable with remarkable uniformity through the entire length of the central or axial basin. The upper beds in the escarpment are of vivid red; the lower part is mainly of a dull greenish-gray color divided by a narrower band of red similar to the brighter-colored strata above. At places the overlying red seems to encroach irregularly upon the gray beds below, but on close inspection it may be seen that this appearance is due to wash and slide and to the stain derived from the overlying material.

The view given in Pl. IV, *B*, is taken from the summit of the cross-bedded white sandstone ridge at the south side of Blue Mountain, and shows the structure and topography of that part of the field. The structure, as explained above, is that of the southern margin of the Midland uplift, with southward-dipping strata of the Jurassic white sandstone in the foreground and the Dakota and Benton ridges to the right and in the distance. The valleys represent the weaker beds that have been eroded. The escarpment in the background to the left is that of the " red beds " in the Midland Ridge.

Like the Raven Park uplift this fold is not symmetrical but dips more abruptly on the south than it does in other directions. It is also limited on the north by a still higher upthrust of similar and related structure. The Midland fold pitches down and terminates abruptly toward the west within a mile or two of the Colorado-Utah State line. Throughout the greater part of its extent its principal axis of flexure lies in an approximately due east-west course, parallel to the larger uplifts of the Uinta system on the north. The Midland fold extends toward the east, its axis bending southward in the upper valley of Wolf Creek, and crosses White River at the

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mouth of that creek. In this portion of its course the axis conforms to the trend of the Raven Park anticline, as it does also with the prevailing structures of all the flexures southwest of this region. Southeast of White River the Midland fold flattens and is lost to view in the lightly dipping strata of the high plateaus of Tertiary strata composing the interior of the Grand River Basin to the south.

RED WASH SYNCLINE.

The Raven Park anticline is separated from the Midland uplift by a syncline or depression of the rock strata. This axis of depression enters the Raven Park district from the east, passing approximately along the channel of White River in the vicinity of Angora post-office. From this point it follows a course somewhat north of west, crossing the valley of Red Wash along the eastern margin of the territory represented on the map. It there produces a broad area of low, rolling country, where lightly dipping sandstone ledges of the Mesaverde formation form the principal outcrops along ridges and gulch sides. The varicolored marls of the overlying Tertiary beds remain along this axis in White River valley and extend westward as far as the twelfth auxiliary guide meridian. The axis of the syncline rises to the west and this fold consequently narrows in that direction. This axis may be readily traced westward as far as Willow Creek as a clearly defined flexure of the strata. Beyond that place, with a slight confusion of dips and strikes, as has been explained (pp. 33–34), the strata assume a lighter dip and the syncline is much less marked. It may be traced, however, as a gentle flexure almost as far west as the State line, where it is lost in the same coalescence of subordinate structures into which the Raven Park anticline disappears.

DOUGLAS CREEK UPLIFT.

The Raven Park anticline is terminated on the south by a narrow and rather abrupt syncline separating the uplift from another low anticlinal structure in the valley of Douglas Creek, farther south. This is a broad, low arch of far greater areal extent than the Raven Park fold, but of less intensity of uplift, so that the strata exposed at the crest on the eroded surface and in the valley bottoms are mainly those of the Mesaverde formation. It occupies chiefly the drainage basin of Douglas Creek, a broken, somewhat roughly mountainous district surrounded by the higher escarpment ridges and plateaus of the Tertiary strata. This broad basin of anticlinal structure extends westward approximately to the State line in the vicinity of Dragon, Utah, and is terminated on the south by the high summits of the divide on the Roan or Book Cliffs Plateau. It is limited on the east by the high, precipitous wall of the Cathedral Bluffs. The areal

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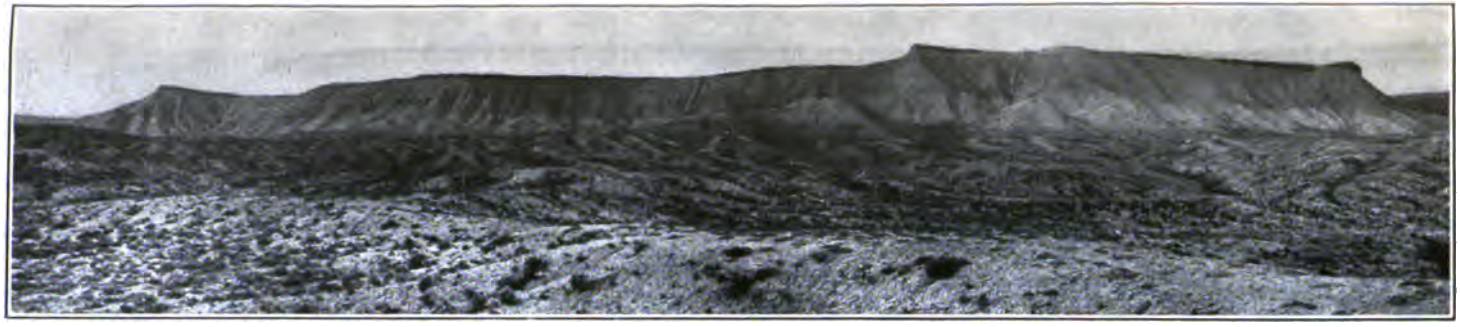

A. THE "RIM ROCK" IN RAVEN PARK.

B. SOUTHERN MARGIN OF BLUE MOUNTAIN.

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extent of this fold is estimated as at least 250 square miles. A large part of this district is coal bearing, and it may eventually prove to be an important coal field.

This uplift lies intermediate between the Raven Park anticline on the north and the uplifted area south of Grand River which forms the northern margin of the Uncompahgre Plateau. It thus completes a north-south series of dome structures which constitute a natural separation of the Grand River Basin of Colorado from the Utah portion of the Uinta Basin, a feature that has already been referred to.

The dips on the flanks of this broad, low fold are very gentle, but there are many irregularities, and the main fold is not, therefore, so well defined nor so readily discerned as the simpler uplifts to the north. The prevailing dips over the larger part of the district are approximately equivalent to the grades of the streams. The oldest strata are exposed on the West Fork of Douglas Creek about 3 miles above the N Bar ranch. Here a small topographic basin is eroded in a shale that clearly belongs near the base of the Mesaverde, but the writer is not certain whether it actually occurs below the lowest sandstone corresponding to the "rim rock" of Raven Park or is just above that bed. By analogy with the Rangely field, the anticlinal structure of this little basin may be considered indicative of a field favorable to prospecting for oil. According to the best information obtained by the writer, however, no indications of oil have been found at the surface and no drilling has been done to determine its presence in strata below the surface.

It is perhaps important to note that the whole region south of the fortieth parallel was erroneously mapped and described in the reports of the Hayden Survey as occupied by the Wasatch formation.[a] For this reason the distribution of the rock formations in this region has not been correctly represented in other publications, nor has its probable economic value as a coal field been appreciated.

UPLIFTS IN ADJOINING REGIONS.

Domes or anticlines similar to the Raven Park uplift occur in many places in the Cretaceous and Tertiary strata west of the Rocky Mountains. Agency Park, the valley in which Meeker is situated, is eroded on a dome that closely resembles the Raven Park fold and exposes the same formation at its crest, although it is of somewhat greater extent. A number of similar, though less conspicuous, folds occur in the Danforth Hills north of Agency Park.

[a] Endlich, S. F., Report on geology of White River district: Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1878, pp. 63–131.

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An anticline similar to the Raven Park fold, but less pronounced in size and intensity of folding, crosses White River between Raven and Agency parks, at White River post-office. This fold is of some interest as a prospective oil and gas field and is described on page 48.

The Rock Springs uplift in southern Wyoming is a well-known feature, similar in form although of considerably greater extent than either the Raven Park or Agency Park uplift. The Mancos shale is exposed at the center of the Rock Springs uplift, as in the other folds, surrounded by ridges of the coal-bearing Mesaverde formation.

DISTRIBUTION OF STRATA DEPENDENT ON INTENSITY OF DEFORMATION.

The occurrence and distribution of the Tertiary formations in this general region is largely dependent on lack of disturbance in the areas they occupy. They are found in the interior portions of the major structural basins, and in their horizontal or slightly inclined position they constitute the high plateaus which characterize those areas. In normal or horizontal position these beds are little affected by the disintegrating action of surface waters and the elements, except where subjected to the actual corrasion of the streams, and in such places they are chiefly cut away by the attrition of the material mechanically transported over them. The streams cut vertical or steep-walled gashes whose sides retreat but slowly into the neighboring uplands. The recent geologic age of these rocks and their consequent position near the top of the stratigraphic column usually account for their entire disappearance over areas that have been uplifted even to a moderate degree. Their softness and lack of coherence has caused them to be removed from the more abrupt portions of the folds, and their outcrops in folds or tilted positions are usually occupied by low valleys.

Both the Wasatch and Green River formations were involved in the folding that produced the uplifts that have been described. This is shown in certain favorable localities where beds of the younger groups are tilted in the same flexures with the older beds.

FAULTS.

So far as has been observed, faults are not of common occurrence in the Rangely district. A possible fault is marked by an offset in the line of hogbacks developed on the "rim rock" at the upper end of the canyon of White River below Raven Park, near which an oil spring was discovered, as described below. Although this particular locality was not examined with sufficient care to enable the writer to reach a satisfactory conclusion, the very evident offset of the lower hogback ridges is thought to indicate very probably a minor

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displacement. Several faults in the Douglas Creek valley showed vertical displacements up to 200 feet or more, but these are south of the area included in the accompanying map. Extensive faults are described along the major axes of uplift in the Uinta Mountains, but these are chiefly north of this area and probably have no effect on the accumulation of oil in this field.

DEVELOPMENT OF THE OIL FIELD.

DISCOVERY OF THE OIL.

Attention was first directed to Raven Park as an oil field by the discovery of an oil seep in a spring at the lower end of the park. This spring is said to have been situated on the north bank of the river, near the location of the new land-survey corner between secs. 5, 6, 7, and 8, T. 1 N., R. 102 W. At the present time the position of this spring seems not very well known, and inquiry as to its location was met with the reply that it is probably trampled down by cattle and its flow obscured in the mire. After the report of this discovery a number of companies were organized among the local residents of Meeker and vicinity to prospect and develop the new field. The whole field is now covered by unpatented locations of the so-called "oil placer claims," the various holdings being still divided under the names of the companies by which they were originally taken up. The total area thus controlled is approximately 45,000 acres, or about 70 square miles.

LOCATION OF CLAIMS.

The original claims were staked and surveyed from the accepted corners of the old land surveys. Since their location, however, a resurvey of the whole territory has been authorized by Congress,[a] and the completed plats are now in the General Land Office in Washington and in the surveyor-general's office in Denver. It is the general understanding that lands filed on previous to the completion of the resurvey are subject to patent as filed, even though their outlines do not conform to the lines or corners of the new survey, unless it shall be mutually agreed by all parties concerned to shift the boundaries to correspond to the reestablished survey lines.

DESCRIPTION OF WELLS.

The first well drilled in the field was known as the Pool well, and was put down in the summers of 1901 and 1902. This well is situated in the SE. ¼ NW. ¼ sec. 33, T. 2 N., R. 102 W. (new survey). In this project three of the Meeker companies combined interests in equal shares with the avowed intention, from the beginning of the work, of sinking through the shale to reach the Dakota sandstone.

[a] Act approved May 28, 1904.

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All work in the early developments was planned in accordance with the erroneous estimates of the thickness of the rocks now called Mancos shale, as given in the Hayden reports. The Pool well was drilled to a depth of 2,130 feet, although an oil-bearing sand with a flow said to have been a barrel or so a day was struck at a depth of 750 feet. The hole became crooked, and for this reason it was finally abandoned and lost.

Three wells were sunk by the Requina Company, of Meeker. The first, known as Requina No. 0, was drilled in 1902 in the SE. ¼ SW. ¼ sec. 21, T. 2 N., R. 102 W. (new survey). Oil struck at a depth of 480 feet is reported to have yielded a flow of several barrels a day, as tested by the bailer. The well was continued to a depth of 600 feet, when it also became crooked and was abandoned. The following notes were obtained from memoranda kept by Maj. L. W. Boutwell, who was present at the time the work was done:

Nov. 13, 1902: Shut down at Requina No. 0 on account of broken injector pump.

Nov. 24, 1902: Pump repaired and started bailing well.

Nov. 25, 1902: Completed bailing of well. Total result was six water tanks filled, holding 5 barrels each, a total of about 30 barrels. This would indicate an average of about 3 barrels per day.

The oil obtained was poured out on the ground and burned.

The Requina No. 1 was drilled a few feet distant from well No. 0, which had just been abandoned, striking the same oil-bearing sand at the same depth. This work was done in 1902 and 1903. Drilling was continued to a depth of 1,680 feet, when a bailer and 1,000 feet of sand line were lost in the hole, and this well was also abandoned. When this well was visited on August 19, 1907, a test of its capacity was in progress, a pump, engine, and small derrick having been temporarily installed for this purpose. The oil obtained was being burned under the steam boiler. A sample of this oil obtained directly from the well and representing the fresh product has been analyzed by Dr. David T. Day, of the United States Geological Survey, and the results are given on page 50.

The Requina No. 2 was sunk in the valley close to the channel of Stinking Creek, about 4 miles north of White River, in the NW. ¼ NW. ¼ sec. 20, T. 2 N., R. 102 W. (new survey). Work was done on this well at intervals from 1903 to 1906. At the time of visit (August, 1907), a derrick and a couple of driller's cabins were still standing. Reports state that water was struck at a depth of 80 feet in coarse, gravelly material, which is said to have been the base of the valley wash, or "adobe" overlying "bed rock." This water is almost certainly the underflow of Stinking Creek; no water has ever been struck in any of the wells within the Mancos shale. It is reported that some gas was found at a depth of about 400 feet, but that no oil

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was obtained from this well. The drilling was continued to a depth of 2,560 feet, but was finally abandoned because of the accidental parting of the casing and the loss of several hundred feet of it in the hole.

All the Requina wells were drilled with the intention of continuing through the Mancos shale to the Dakota sandstone. Each hole was lost or abandoned through accident.

Two wells were sunk by the Meeker Company, also of Meeker. Both of the wells of this company were drilled to the first oil horizon and discontinued at or near that depth. The well known as Meeker No. 1 is situated in the NW. ¼ NW. ¼ sec. 28, T. 2 N., R. 102 W. (new survey), about one-fourth mile southwest of the Requina wells Nos. 0 and 1. This well is said to have struck oil at a depth of 736 feet, and the hole was drilled to a total depth of 771 feet. At present the site is marked by a metal tank partly filled with oil. This well is said to have shown a flow similar to or slightly less than that of the near-by Requina wells.

The Meeker No. 2 was sunk in 1903, almost exactly 1 mile due east of the Meeker No. 1, in the NW. ¼ NW. ¼ sec. 27, T. 2 N., R. 102 W. (new survey). The well is said to have struck what were thought to be the same oil-bearing sands as those found in the wells already described at a depth of 1,002 feet, when work was discontinued. No oil was obtained from this hole.

The second attempt, by combined interest, to prospect the so-called "deep sands" (meaning thereby the supposed oil pool in the Dakota sandstone) was made in 1903 by drilling the well known as the Union. The site selected was on the northeast side of Raven Park, slightly over half a mile from the "rim rock," in the middle of the west side of sec. 16, T. 2 N., R. 102 W., near the quarter-section corner of the new survey. The adoption of this site was based on an application of the anticlinal theory, as explained on page 34. On the assumption that oil would be found on the flanks of the anticline and that gas would occupy the summit, the site was selected near the margin of the basin, a location giving nearly the maximum thickness of the shale body available from the valley to be passed through before the Dakota sandstone could be reached. This well, known as the first Union, was commenced in 1903 and the hole drilled to a depth of 1,300 feet. Oil was found at a depth of 584 feet, but was cased off and the drilling continued. The hole was finally abandoned owing to the loss of a string of tools due to collapsing casing.

The second Union well was put down on approximately the same site as the first, striking the first oil sand at the same depth as before. This well was also commenced in 1903 and continued at intervals until April 15, 1907, when the rig took fire while still at work and the whole surface equipment was lost. The depth of the hole is

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3,655 feet, and the well is said to be still in good condition. It is cased to a depth of 2,974 feet with a string of casing made up of 1,228 feet 8½-inch, 1,332 feet 6⅝-inch, and 414 feet 5-inch.[a] The following is a record of the strata passed through; it is said to be somewhat incomplete on account of the destruction of a part of the data at the time of the burning of the rig:

Record of second Union well, Raven Park.

[Sybert and Joe Trachta, drillers.]

	Thickness.	Depth.
	Feet.	*Feet.*
Shale, dark, at bottom of which small oil-bearing was struck	584	584
Shale, dark	816	1,400
Shale, light colored	200	1,600
Shale, dark, much of it of purple color	839	2,439
Shale, very light colored, drillings being nearly white	41	2,480
Sand, shaly	5	2,485
Shale, dark, with fine lines of white, very rotten	194	2,679
Sand, flinty, alternating with rotten shale	58	2,737
Shale, dark	343	3,080
Shale, black, a little sandy	170	3,250
Shale, hard, black, alternating with light-colored shale	405	3,655

From the manner in which the drill was worn it is supposed to have penetrated hard sandstone at the bottom of the well. This bed is locally supposed to be that of the Benton horizon already described (p. 15), and is reported to have contained fossils, none of which, however, were saved.

In the summer and fall of 1907 several new wells were drilled and some of the older wells were systematically pumped as a test of capacity, under the supervision of Mr. J. H. Hunt, of Haywards, Cal. Of the older wells the only ones available for the test were the Meeker No. 1 and the Requina No. 1. At present writing (December, 1907) it is understood that this work is still progressing and that systematic prospecting of the field will be pushed. It is also reported that five new wells have been drilled, of which four are claimed to have struck oil. Mr. Hunt gives the following statement with regard to his work in the field:

Altogether my experiments and tests show that oil is found in all the wells except two, at depths from 400 to 700 feet below the surface. The wells cover a distance of about 3 miles from north to south and 1½ miles from east to west. The oil is of a uniform character and in all wells rises to the same level, approximately 360 feet below the surface. By continued pumping the production increases. The formation in which the oil is found is sand and shale mixed, varying in thickness from a few feet to 45 feet. By shooting with nitroglycerine the flow is apparently increased, although we have not yet experimented sufficiently to determine the size shot which is most effective. The production of both the wells shot was increased, but the formation is so hard that neither well was caved in, indicating that they will stand a still heavier shot without damage.

[a] Information received from Mr. Henry J. Hay, of Meeker.

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OCCURRENCE OF THE OIL.

ATTEMPTED APPLICATION OF THE ANTICLINAL THEORY IN THE RANGELY FIELD.

The scientific study of an oil or gas field from the standpoint of the geologist is the only means worth consideration by which the probable presence or absence of these substances in depth may be predicted in advance of actual drilling. In such a study lies the only hope of eliminating any of the large number of failures and the consequent loss of capital so often involved in random drilling in the search for productive sites. However, no geologist or mining engineer can yet recognize with certainty the essential criteria that determine productive pools, nor can he say even in a well-known field what new locations will prove productive. At best such statements can be no more than mere probabilities. In a new field conditions are still more uncertain, and specific knowledge of the occurrence of oil can be obtained in no other way than by actual drilling. An intelligent study of the geologic structure and the formations is the only means of arriving at even a partial understanding of the occurrence of the oil or gas.

The interests that have controlled the prospecting in the Rangely oil field have been for the most part local, distributed among the older residents of the country, who were personally acquainted with the field and with the work that was being done. All of the preliminary drilling seems to have been directed by an intelligent effort to apply the structural or anticlinal theory of the accumulation of oil and gas, which has appeared to explain so successfully some of the oil pools found in the fields of West Virginia and adjacent States.[a]

C. A. White, in the Hayden report, described this valley as eroded from the crest of an anticline or dome and suggested it as a field favorable to the location of artesian wells, should they ever be desired—a prediction which he also stated was based wholly on its geologic structure. With the discovery of oil, the prediction of artesian conditions suggested flowing oil wells. The anticlinal structure of the field suggested, further, the application of the anticlinal theory in this region. Several wells have now been drilled to considerable depth in search of the Dakota "sands." This formation has been thought to fulfill the assumed requirements as a principal storage reservoir for the oil. The theories on which these assumptions are based are briefly reviewed in the following paragraph. In the application of these theories the estimates of the Hayden report for the thickness of the Mancos shale (then termed Colorado and

[a] White, I. C., The Mannington oil field [West Virginia] and the history of its development: Bull. Geol. Soc. America, vol. 3, 1892, pp. 193–216. The geology of petroleum and natural gas: Rept. West Virginia Geol. Survey, vol. 1, 1899, pp. 155–195.

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lower part of the Fox Hills) were at first accepted. The figures and sections of that report indicated that the Dakota would be found at no great depth in the valley lands. The wells that have been drilled as yet have failed to reach the base of the shale and it is now clear that the first estimates of its thickness were far too small.

It is undoubtedly true that in many or most oil fields some well-defined relationship exists between the structure—that is, anticlines and synclines in the strata—and the distribution of the oil pools. It is probable also that this relationship is not so simple as exponents of the anticlinal theory from time to time have been led to believe.

After the discovery of the oil spring, attention was attracted to Raven Park as an oil field by the suggestion of its quaquaversal [a] structure, which has been commonly referred to locally as a "perfect anticline." It was at once inferred that in this area were to be found the ideal conditions for the accumulation of a large body of oil, according to the postulates of the anticlinal theory. The conditions assumed by the anticlinal theory as controlling the accumulation of oil and gas are briefly as follows:

(*a*) Porosity of a reservoir rock, which is commonly a stratum of sandstone or sandy rock, capable of containing the oil supply in the interstices between the sand grains. This is generally known as an oil sand and is in many places of sandy composition, although it may be a fractured shale, or even limestone, sufficiently porous to allow the accumulation of oil.

(*b*) An impervious cover or cap rock to serve as a seal and prevent the escape of the oil and gas in an upward direction.

(*c*) Geologic structure or folds in the rock, favoring the accumulation of the oil and gas in certain localities by draining these substances from more extensive areas of adjoining beds less favorably situated for their retention.

(*d*) Saturation of the rocks by ground water, on which the oil will move by reason of its lighter specific gravity, and therefore be forced into the upper parts of the folds—that is, toward the crests of the anticlines.

Oil and gas are commonly found together. According to this theory the gas may be expected above the oil. It is most frequently found in the crests of the anticlines. Small folds or irregularities in the rock structure may hold some of the gas farther down the flanks of the anticlines, or even in parts of the synclines; or, as another condition, less permeable portions of the reservoir stratum may also imprison both the oil and gas below the summit of the fold.

This theory is based on the assumption of the presence of water in the oil sand. Experience has shown, however, that although partial

[a] "Dip of strata in all directions away from a center."—White, C. A., Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1878, footnote, p. 42.

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saturation is the condition most generally encountered, yet at a great many places, in both the eastern and the western oil fields, no water is present. These conditions present many modifications of the original theory. Thus the oil may be found almost anywhere with reference to the geologic structure, its position in many localities apparently depending largely on the presence or absence of ground water. The places of accumulation in dry rock are thought to be at or near the bottom of the synclines, or the lowest point of the porous medium, or at any point where the slope of the rock is not sufficient to overcome the friction that retards the movement of the oil. In porous rocks only partly filled with water the oil probably accumulates at and just above the ground-water level, or above the level of saturation. This level may be fairly constant in one basin or structural feature, but probably varies greatly in different basins or in different sands in the same basin. As most of these considerations depend on the position of the ground water and its relation to the oil, they do not seem to apply to a discussion of the oil as it is found in the Rangely field.

In the first attempted application of the anticlinal theory to the Rangely field, it was pointed out that the Mancos shale (then known as the Colorado and Fox Hills) would furnish the required impervious cap rock. The Dakota sandstone, locally referred to as the Dakota "sands," was assumed to form the requisite porous stratum for the storage of the oil. Attention was called to the fact that White had already predicted that the Dakota would be a source of artesian water, and this water was therefore expected to provide the degree of saturation required to cause the oil to rise into the anticline and to afford a hydrostatic pressure which it was supposed would also produce flowing wells. The spring containing oil at the lower end of the park was thought to be a seepage from this reservoir along a somewhat indefinite fault. (See p. 38.) The first wells drilled in the field were therefore put down with a view to penetrating the overlying shale as far as the Dakota sandstone. The numerous failures from one cause and another to accomplish this aim have been described.

GEOLOGIC RELATIONS IN THE RANGELY FIELD.

The wells that have been drilled in the Rangely field have discovered one or more oil-bearing sands in the body of the Mancos shale. But one oil sand has been found in any one well, and there seems to be a rather indefinite belief or assumption on the part of the local operators that this lies everywhere at one and the same horizon. If the reports of the depths of the oil sand are correct, this assumption does not seem to be warrantable. Any single horizon at the depths

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recorded in the various wells would not accord with the recognized general structure of the field.

Records kept by the drillers and observations at the outcrops of the Mancos shale show the existence of beds of more or less sandy composition at various horizons within the formation. The well records obtainable are incomplete and not very specific in their description. There seems to be considerable uncertainty, even among those who are most familiar with the work as it was done or who have actually done the drilling, as to the precise nature of the beds in which the oil was found. In a personal communication Mr. Henry J. Hay, of Meeker, states:

> As to the thickness of the oil sand I can not say exactly. Sybert, who drilled the Union to the first sand, thought not over 2 feet, and perhaps less; but Trachta thinks it is greater. No other sand beds were found except in the Union well.

The following note was received from Mr. Joseph Trachta, who has had charge of most of the drilling in the field:

> In regard to the layer where they strike the upper strata of oil I wish to say that it is not a sand layer. It is a hard gritty shale. It is much grittier than the other shale. It looks very much the same all the way through, only a little darker. The gritty shale I speak of is about 100 feet thick and you strike oil through that 100 feet somewhere. The same gritty shale will not decompose to clay as quickly as the other for the reason that it is harder, but is not like the sand we struck at the bottom of the Union well, for that was sand.

The quotations given above are at present the only available descriptions of the nature of the beds that contain the oil as they have been encountered in the wells.

The oil-bearing sands of the Rangely field are probably more in the nature of lenses forming completely inclosed and isolated reservoirs than of "pools" in the sense implied by the anticlinal theory. This conclusion is based mainly on a study of the general characteristics of the strata observed at their outcrops, for the small amount of well drilling that has been done in the field has not supplied sufficient data from which to determine this feature. The lenticular character of almost all the individual beds observed along the outcrops of the Mancos and associated formations is strong presumptive evidence of their similar discontinuity in depth. Like all the minor members of the Cretaceous strata in general, particular beds are found to thicken and thin from place to place along their outcrops or even to disappear entirely, some of them very abruptly, although the features which characterize these particular beds recur at many places at what appears to be the same horizon, over widely extended areas. This irregularity of bedding is more marked in the smaller or thinner strata than in the more prominent members.

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Sandy beds, or even strata of fairly massive sandstone, are known to occur along the outcrop of the Mancos shale at some localities outside of Raven Park. An example may be noted in Agency Park, where such sandy beds form a minor hogback in the valley of Mancos shale. Similar beds are present in the upper valley of Coal Creek east of "The Transfer," in eastern Rio Blanco County.[a] So far as known there are no beds in the Raven Park district as prominent as these just cited. From the descriptions of the well drillers, however, it is assumed that some minor beds of this character do occur. In all of this discussion it is recognized that the zones of oil accumulation commonly referred to as sands may not be true sands, but merely porous strata of any constitution in which the oil can gather. The variability and discontinuity of the rocks described are not, however, confined to any one particular feature, such as their sandy composition, as has frequently been observed in the field, but seem to be shown no less by all other physical characteristics and therefore probably apply with equal certainty to the feature of porosity.

The oil-bearing sands that have been struck have been entirely free from water and apparently from the influence of any hydrostatic pressure. The body of the shale itself appears to be wholly barren of water, to which it seems to offer an impervious barrier. If the oil bodies of the Rangely field are in truth contained in isolated or completely inclosed reservoirs they can hardly be expected to exhibit artesian conditions to any marked degree. If, however, a tilted reservoir is tapped somewhere below the upper surface of its contained oil this fluid would of course seek its level in the opened well, or might even be forced higher by a pressure of gas confined in the reservoir above the oil. In any case, it seems clear that whatever artesian conditions may exist in the Dakota sandstone or below that stratum, they are confined beneath the main body of the impervious Mancos shale and do not affect the distribution of the upper oil bodies.

The presence of oil in the Dakota sandstone appears to be a problem of purely speculative nature which can be proved only by the drill. No evidence of oil has ever been found in the outcrop of the Dakota beds in the neighborhood of the Rangely field. The inference of its presence in those beds is therefore based entirely on the supposition that their constitution offers a reservoir particularly well adapted to oil accumulation. This is entirely within the bounds of possibility, as is also the existence of artesian conditions in view of the structure and exposure of the Dakota strata in the apparently favorable catchment area at the south side of Blue

[a] Illustrated in the cross section published with the geologic map of that district in Bull. U. S. Geol. Survey No. 315, 1907, Pl. III.

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Mountain. Oil is reported as occurring in the Dakota sandstone at Turkey Creek and near Golden City, in the Denver Basin.[a]

THE WHITE RIVER FIELD.

In connection with a discussion of the occurrence of oil in the Rangely field, it is interesting to note that some indications of a similar field have been noted on Blacks Gulch, 40 miles east of Rangely in the White River valley. Blacks Gulch opens into White River from the north 20 miles below Meeker. It is near the crest of a minor anticlinal fold, the longer axis of which crosses White River in a north-south direction near the mouth of Piceance Creek at White River post-office. This fold is a low dome of the rocks, exposing the Wasatch strata at the surface, surrounded by escarpments of the Green River formation on all sides. The dips are all light, being about 3° toward the east, increasing to 10° or so south of the river and to about 5° toward the west. Gas is said to have been found by Tom Scarritt, a cowboy, by the accidental igniting of a small flow from a lighted match. A small derrick was set up and a hole drilled to a depth of 400 feet and abandoned. According to reports, a second well was sunk about half a mile farther up the gulch. Here at a depth of 538 feet gas was struck under such pressure that the derrick was destroyed and the driller seriously injured. The gas burned with a blue flame and under much pressure for six months, when it stopped abruptly. The fact that the tools have been left in the hole leads to the supposition that it became suddenly blocked. Gas is also said to be issuing along this same anticline south of the river, at the locality known as Alkali Flats. So far as known no oil has yet been obtained in this field. It resembles the Rangely field only in its geologic structure, the strata being of much later age and overlying by many thousands of feet the oil-bearing beds of the Rangely district.

COMPARISON WITH OTHER KNOWN FIELDS.

Oil has been found at approximately the same geologic horizon as in the Rangely district in a number of fields of this same general region, notably in other parts of Colorado and in Wyoming. Among these may be cited the Florence and Boulder fields,[b] and some flows or seeps in the eastern part of Routt County, Colo. In Wyoming a basin similar to the Raven Park basin in structure and topography has been prospected east of Rock Springs, on the Union Pacific Railroad. It is understood that the work at that locality was undertaken

[a] Lakes, Arthur, Oil in Colorado: Mines and Minerals, vol. 22, 1902, p. 257.

[b] Fenneman, N. M., The Boulder (Colorado) oil field: Bull. U. S. Geol. Survey No. 213, 1903, pp. 322–332; Bull. No. 225, 1904, pp. 383–391; The Florence (Colorado) oil field: Bull. No. 260, 1905, pp. 436–440.

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wholly from the suggestion of the anticlinal structure of the field. Although several holes were sunk to a considerable depth in the Mancos shale, it is said that neither oil, gas, nor water was found in that formation. Occurrences of oil in Uinta County, Wyo., some of which are at a horizon analogous to that of the Rangely oil, are described by Veatch and Schultz.[a]

It has been suggested by some of those interested in the Rangely field that conditions here may be held to be more comparable with those of the California fields than with those of the oil fields of the eastern United States. It is believed, however, that this view is not well founded. The California fields are of great complexity of structure, the oil occurring in almost every conceivable structural situation—along faults, in synclines, or in anticlines—and it is thought that no clear understanding has yet been reached of the conditions controlling the accumulation of oil in certain beds there. No direct relationship can be traced to the situation in the Rangely field.

It has also been suggested, and probably with more reason, that the Rangely field may be compared to the Kansas-Oklahoma oil and gas fields.[b] In those districts the oil, though occurring in a much older formation geologically, is said to be found in sandstones interbedded with shale, in lenticular bodies or completely inclosed reservoirs. The geologic structure of those fields is, however, much more simple than that of the Rangely field, being that of a fairly uniform monocline, with a northwesterly to westerly dip of about 20 to 25 feet per mile.

QUALITY OF THE OIL.

PHYSICAL PROPERTIES.

The color of the Rangely oil is clear light red, with strong green fluorescence, closely resembling that of many of the Pennsylvania oils, although perhaps slightly darker than the average. Its odor is like that of kerosene, much resembling that of a refined oil. It is apparently free from sulphur. The specific gravity of the crude oil from Requina well No. 1 is 0.8092, or 44° Baumé. It would therefore be described as a very light, thin oil.

[a] Veatch, A. C., Coal and oil in Uinta County, Wyo.: Bull. U. S. Geol. Survey No. 285, 1906, pp. 331–353; Geography and geology of a portion of southwestern Wyoming, with special reference to coal and oil: Prof. Paper U. S. Geol. Survey No. 56, 1907. Schultz, A. R., The Labarge oil field, central Uinta County, Wyo.: Bull. U. S. Geol. Survey No. 340, 1908.

[b] Adams, G. I., and others, Economic geology of the Iola quadrangle, Kansas: Bull. U. S. Geol. Survey No. 238, 1904. Schrader, F. C., and Haworth, E., Economic geology of the Independence quadrangle, Kansas: Bull. U. S. Geol. Survey No. 296, 1906.

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CHEMICAL PROPERTIES.

An analysis of the Rangely oil, reported as made by the Standard Oil Company, and already used in the published notes and descriptions of the Rangely field, is as follows:

Analysis of Rangely oil.

[By Standard Oil Company.]

Crude oil, gravity, 43.6° Baumé; burns at 60°.	Per cent.
Light naphtha, gravity, 70.3° Baumé	7
Heavy naphtha, gravity, 61.1° Baumé	12
Illuminating oil, gravity, 45.1° Baumé; flashes at 90°; burns at 116°	60
Paraffin, gravity, 32.8° Baumé	20
Coke and waste	1

The oil is free from sulphur compounds.

A sample of the oil collected fresh from the pump that was running at the Requina No. 1 well on August 19, 1907, was distilled by Dr. David T. Day, of the United States Geological Survey, giving the following results:

Analysis of Rangely oil from Requina No. 1 well.

[By David T. Day.]

Initial boiling point, 48° C.	Per cent.
Gasoline and naphtha (below 150° C.), specific gravity 0.68	25
Illuminating oil (150° C. to 300° C.), specific gravity 0.751	45
Residue (above 300° C.)	27
Loss	3

The oil contains no water. The residue contains much paraffin wax, and there is no asphalt in the sample.

WATER SUPPLY OF THE RAVEN PARK DISTRICT.

GENERAL.

The question of water supply is important to all interests in Raven Park and vicinity, whether engaged in agriculture, stock raising, or the development of natural resources. The annual rainfall is small, and the climate may be described as semiarid. West of the Rocky Mountains the aridity of this plateau province becomes more and more pronounced away from the higher mountain masses, and Raven Park may be said to lie on the border land between the badlands, or more typically desert regions farther west, and the productive basins and valleys of the mountain foothills. A great extent of pasture lands of much value to stockmen is available here only

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as a winter range when the snow lies on the ground, being wholly destitute of water during the summer season. This is especially true of the territory south of Raven Park and west of Douglas Creek, locally known as the "park country" and designated on some of the maps Rabbit Hills.

AVAILABLE SUPPLIES.

Near the Rangely district only White River and two of its principal tributaries, Douglas Creek and Spring Creek, retain water in their channels throughout the year. In drier seasons both these creeks are said to dry up in the summer, although they have flowed continuously for the last two seasons. The water supply of the Raven Park settlement, both for domestic use and for irrigating the land, is taken from White River, which flows with a good volume and a moderately swift current throughout the year. The stream has a normal width through Raven Park of 2 to 4 chains, or an average of about 200 feet. It pursues a meandering course through the bottom lands, but has a number of slight rapids or riffles over bowlder and gravel bottoms. Its average rate of fall across the park is about 12 feet per mile in a straight course down the valley, and about the same in the canyon above the park. Recent gagings of White River by the United States Geological Survey are quoted in the following tables:[a]

Discharge measurements of White River.

At Meeker, Rio Blanco County, Colo.						At Ignacio, Uinta county, Utah.[b]					
Date.	Width of river.	Area of cross section.	Mean velocity.	Gage height.	Discharge.	Date.	Width of river.	Area of cross section.	Mean velocity.	Gage height.	Discharge.
1906.	*Feet.*	*Sq. ft.*	*Ft. per sec.*	*Feet.*	*Sec.-feet.*	1906.	*Feet.*	*Sq. ft.*	*Ft. per sec.*	*Feet.*	*Sec.-feet.*
						Apr. 17	72	184	3.19	3.60	587
						Apr. 18	73	198	3.43	3.78	679
Apr. 23	79	267	3.67	4.60	980						
May 4	79	240	3.11	4.39	747						
						May 13	80	506	4.56	6.60	2,308
May 17	78	328	6.42	5.50	2,097						
May 22	78	380	8.57	6.15	3,256						
May 31	78	343	6.94	5.65	2,383						
June 8	78	336	6.69	5.56	2,249						
June 23	78	310	6.41	5.47	1,988						
						June 24	89	631	3.10	6.20	1,955
July 3	78	267	3.76	4.60	1,014						
						July 19	72	285	3.27	4.28	931
July 24	78	187	3.48	4.06	651						
Aug. 10	78	167	2.11	3.85	356						
Aug. 20	78	172	2.15	3.90	369						

[a] Discharge measurements at regular stations; estimated monthly run-off based on daily readings of gage height for stations named.

[b] 18 miles northwest of Dragon, Utah.

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Estimated monthly discharge of White River.

At Meeker.		At Ignacio.	
Date.	Total in acre-feet.	Date.	Total in acre-feet.
1906.		1906.	
April	37,400	April	47,800
May	129,000	May	123,000
June	151,000	June	133,000
July	51,400	July	58,400
August	22,800	August	38,600
September	20,500	September	42,100
October	18,000	October	34,400

White River has its principal headwaters in the wooded "Flat-tops" of the White River Plateau, 70 or 80 miles east of the Rangely field. In its upper course, or above Agency Park, this stream is normally a clear, fresh mountain stream. There are some scattering settlements and irrigation along the narrow bottoms in this upper valley, but the volume and swift current of the river at that part of its course seem ample security against appreciable deterioration in the quality of its water. In Agency Park the stream enters on the areas of younger and less consolidated Cretaceous strata, and from this point down the water rapidly loses the freshness and clarity of its upper course. Many ditches divert water for irrigation and return it to the stream more or less charged with alkaline salts from the meadow soils and in practically all cases considerably polluted by cattle and surface refuse. In Agency Park, as also lower on its course during wet seasons, the tributaries empty heavily charged alkaline waters into the main stream, most of that material being leached from the soils of the younger Cretaceous and Tertiary strata.

Below Powell Park the territory drained by the lateral tributaries of the main stream is composed on the north of badland drains of the "Crooked Wash," or Coyote Basin, and the valleys of Wolf Creek and Red Wash, with numerous other smaller drains. From the south side the extensive drainage basins of Piceance and Yellow creeks and other smaller streams from the Roan or Book Cliffs Plateau pour their alkaline waters into the main stream. In times of flood, as in the spring and early summer, and at frequent intervals in the summer months during the brief and violent storms which are characteristic of the region, all of this lower tributary drainage empties a great volume of thick, muddy water into the main channel, making the river water much of the time heavy with mud and clay and surface refuse. At times of such turbidity the river water has a foul odor, suggestive of putrefying flesh, which is, however, thought to come from the clay that is suspended in the moving water. Along its lower course, in the vicinity of Raven Park, White River seldom runs clear for long at a time. The constantly recurring storms at one locality or another in its upper valley keep its water in a condition which is

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by nature distasteful to man and beast. The question of its effect on the animal system is open to much conjecture, and with increasing population of the district may become a vital issue.

OBJECTIONABLE FEATURES OF THE WHITE RIVER WATER.

The normally distasteful condition of the river water during most seasons of the year is evidently a source of growing complaint among the settlers. Whether rightfully or not, to its effects have been attributed various maladies among those more or less in ill health who are compelled to depend on its use. Its most apparent objections are its turbidity and to a less extent perhaps the odor which seems to accompany this condition when extreme. This turbidity is of course due largely to mechanically suspended sediment that settles out readily when the water is allowed to stand undisturbed. In view of this fact it is a prevalent custom among the residents to dip the water first into a settling barrel at the river bank, whence the supply is carried from time to time to the houses in pails. The suspended matter is so fine and sticky that its removal by filtration would be difficult.

An objection hardly less evident than its muddy condition to those who give the subject any consideration is the constant presence of dead and putrefying animals in the tributary channels and also along the main stream. In a country so largely given to cattle raising it is inevitable that many dead animals must constantly lie scattered about the country. It is perhaps an unfortunate instinct that leads the sick and injured animals to these watering places, where their dead bodies very often pollute the supply for all the rest of the herd, if not also for human use. Flood seasons or heavy storms sweep the refuse from such decay into the main stream. It is said that in winter great numbers of cattle break through the ice and are drowned. Their bodies then lodge in the stream until the breaking up of the ice in spring, when they are passed on down the stream with the high waters. The effect of such decaying matter on the water as a whole, though very unpleasant to consider, is perhaps not yet proved to be essentially harmful, in view of the extreme dilution of the objectionable matter with the total volume of water. The organisms of decay of both organic and vegetable matter, though often offensive to the senses, are not necessarily the vitally dangerous elements of a polluted drinking water. The most dangerous elements to human life are certain specific germs of disease, such as those of cholera and typhoid, which propagate and spread only from sources that contain those germs in advance. So long as these diseases are absent from the drainage basin of White River it seems fair to assume that their germs are not contained in the river water.

A further source of objection may be found in the fact that the river water itself may also exert a harmful influence upon the human

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system by reason of its chemically dissolved constituents. These are clearly present to a rather marked degree, so that the water is described as "hard." The hardness of a water is due to the presence of alkaline carbonates such as those of calcium, sodium, and magnesium, or to the alkaline sulphates, chlorides, and nitrates. The carbonates produce what is known as temporary hardness, because it may be remedied by boiling. Water containing the constituents of the second group is permanently hard—that is, it remains so even after it has been boiled. The hardness of the White River water is of the permanent kind.

None of these dissolved constituents are of the nature of actively poisonous substances, but the effect of the water on persons unaccustomed to it or to other similarly hard waters is pretty clear evidence of a certain amount of activity. Chemical analyses of the inorganic constituents may be relied on to define very clearly the nature of these dissolved mineral substances, and a fair estimate of its probable effect on the human system from this cause only may be thereby obtained.

With this purpose in view a sample of White River water was collected by the writer from the main stream just above the Rangely bridge on August 26, 1907. The water at that time was in a somewhat turbid condition, and though the river was not so low nor the water so clear as it had been at times during the month, its condition was not at all an extreme of flood or muddiness, and the sample is considered to represent a very fair average. This water has been analyzed in the laboratory of the United States Geological Survey at Washington, with the following results:

Analysis of White River water collected at the iron bridge, Rangely, Colo., August 26, 1907.

[By R. B. Dole.]

	Parts per million.
Total suspended solids	5,000
Total dissolved solids at 180° C	400

SUSPENDED MATTER.

	Per cent.
Insoluble in HCl (sand, clay, silica, etc.)	71
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	11
Calcium (Ca)	.13
Magnesium (Mg)	.05
Sulphate radicle (SO_4)	Trace.
Organic and volatile matter	16
Undetermined	1.82
	100

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DISSOLVED CONSTITUENTS.

	Parts per million.
Silica (SiO_2)	20
Iron (Fe)	1.5
Calcium (Ca)	66
Magnesium (Mg)	24
Sodium and potassium (NaK)	35
Carbonate radicle (NO_3)	5.5
Bicarbonate radicle (HCO_3)	194
Sulphate radicle (SO_4)	146
Chlorine (Cl)	9.3
	501.30

There is apparently no poisonous mineral matter in the water in sufficient quantity to do any harm. The suspended matter is very high and is of such fine, sticky, or "gumbo" character that its removal by filtration without coagulant would be difficult. The sulphates are rather high and calcium-sulphate scale would doubtless result from the use of the water in boilers. If carefully filtered the water would be sufficiently good for domestic use, but in its raw state it is absolutely unacceptable.

USE OF ICE.

It has been an established custom among some of the older residents of Raven Park and vicinity to preserve ice from the river in winter for their summer supply of drinking water. This custom has several important advantages and is to be heartily indorsed. The ice is obtained when the surface of the river is covered and for the most part securely sealed. Refuse and objectionable matter are in the main frozen also, and decay is arrested, so that very little of such matter can gain access to the flowing water, or if it does it lies essentially inert. The water at this time is derived largely from melted snow and ice collected from a frozen ground surface and so is unusually free from the alkaline salts which enter so largely into its composition in the summer. The process of freezing itself excludes a large proportion of the chemically dissolved constituents. It is well known that the ice formed on the salt water of the ocean includes but a small percentage of the normally contained salt.

SPRINGS.

Aside from White River itself there is but little water to be had over a rather extensive area, especially in the lower valley lands bordering the river basin. A few springs are known among the sandstone ridges bordering Raven Park, and a number of them are indicated on the topographic map (Pl. I). Some of these are of good though usually hard water. The following list gives the loca-

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tion of those that are best known or that were found in the present survey:

Springs and water holes in Raven Park district away from White River.

Name.	Location.	Remarks.
Nate Spring	In Nate Spring Gulch, sec. 34, T. 3 N., R. 102 W.	
Iron Spring	SE. ¼ sec. 35, T. 3 N., R. 103 W.	Not very good.
Flat Rock Spring	SW. ¼ sec. 26, T. 3 N., R. 103 W.	Good water, but small flow.
Iron Spring	In Chase Gulch, NW. ¼ sec. 20, T. 2 N., R. 101 W.	
Three Springs	At old Mobley post-office, sec. 34, T. 4 N., R. 100 W.	Good water.
Box Elder Spring	Sec. 8, T. 3 N., R. 100 W.	
Skull Creek	At Jones's ranch, sec. 1, T. 3 N., R. 101 W.	Do.
Red Wash Creek	Sec. 2, T. 3 N., R. 102 W.	
Willow Creek	Sec. 12, T. 3 N., R. 103 W.	Camping site and stream: good water.
Small stream	Sec. 35, T. 4 N., R. 104 W.	Good water.
Cliff Creek	K ranch, sec. 23, T. 4 N., R. 104 W.	

Beyond the southern and southeastern margins of the district here described, springs and headwaters of streams containing excellent water are found in the wooded slopes close up under the Cathedral Bluffs. The upper courses of the various forks of Douglas Creek are fresh and clear at a distance of 30 miles or more above Raven Park.

To the north, along the southern foot of Blue Mountain, as indicated on the map (Pl. I), there are numerous supplies of good fresh water, though usually in springs or streams of small volume. These have long furnished the excellent camping sites that lie along the old Uinta trail, which follows the valley from the Yampa and White River territory into Utah, forming a part of the route through this country to Salt Lake City. These waters are derived from the various sandstone strata in the older formations that flank the high plateau. They can be readily traced to the points where they issue from these strata in the form of springs, but in their lower courses they dry up soon after reaching the open prairie and valley lands.

Above Jones's ranch on Skull Creek, in the NE. ¼ sec. 1, T. 3 N., R. 101 W., a good flow of water issues from the upper beds of the Carboniferous sandstone, which underlies the brilliantly banded strata of the Midland Ridge escarpment. These waters are rather strongly charged with iron and sulphur, but were found very agreeable to the taste by comparison with the muddy water of the river below.

Box Elder is a camping site situated on the main wagon trail in the middle of the north side of sec. 8, T. 3 N., R. 100 W., about 2 miles southeast of Jones's ranch. A spring of good water is said to issue from the hogback ledges about half a mile above this place.

At Three Springs, which is east of the area shown on the map, on a minor fork of Wolf Creek, in sec. 24, T. 4 N., R. 100 W., the water

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issues from the "White Cliff" sandstone (Jurassic) capping the brilliantly banded strata of the Midland Ridge escarpment. This is a well-known locality to the old settlers and travelers of the region. A ranch, formerly the post-office Mobley (now discontinued), is situated by one of the springs. The springs lie north of the main east-west route of travel, being about 2½ miles from the Yampa River-Utah trail. The approach from Wolf Creek valley is over a somewhat rough and rocky wagon trail, which also continues northward and is one of the routes of access to the summit of Blue Mountain. The water is clear and cool and flows with very good volume from several of the seeps that issue along the hillside within a distance of perhaps half a mile.

A group of springs is also found in the NE. ¼ sec. 2, T. 3 N., R. 102 W., in the west or main fork of Red Wash, at the point where that stream crosses the same Jurassic sandstone ("White Cliff") from which the water is derived at Three Springs. The lowest spring of this group is one of considerable size and flow and is strongly charged with iron. From these springs water flows down the channel of Red Wash for only a short distance, soon sinking and drying up, except in wet weather.

The springs next west of Red Wash are those that form the headwaters of Willow Creek, in the SE. ¼ sec. 12, T. 3 N., R. 103 W. Here also the water issues from the "White Cliff" (Jurassic) sandstone, as at Three Springs and on Red Wash. It gathers in two small branches in the valley north of the Dakota hogback, uniting into a single stream of some little volume as it crosses the wagon road, but sinking soon after it passes out into the valley below.

West of Willow Creek the next spring water found along the Uinta trail is a small stream issuing from behind the Dakota hogback 2 miles south of the K ranch and near the Colorado-Utah State line, in the SE. ¼ sec. 35, T. 4 N., R. 104 W. Here also the water is derived from the Jurassic sandstone already referred to. This stream is very feeble in dry weather, often becoming of very small flow during the day and regaining a somewhat stronger volume at night. It runs but a short distance out into the valley, however, before it sinks and its channel is normally dry.

At the K ranch one of the main branches of Cliff Creek contains sufficient water to irrigate a small field. The water is ponded in a small reservoir near the house and probably would flow for a considerable distance down the main creek channel were it not diverted. A more northerly fork of Cliff Creek lying near the escarpment named on the older maps as Section Ridge is said also to contain water.

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RAIN WATER.

So far as is known to the writer no attempt has ever been made to save the rain water or snow water for domestic use. This is, however, accomplished in a natural way and is occasionally found to serve a very useful purpose. The back slopes of the cuesta or dip-slope ridges surrounding Raven Park are in many places capped by bare ledges of heavy-bedded massive white sandstone. Irregularities in these nearly horizontal beds retain the rain water of the summer showers, which frequently form innumerable pools, some very large and deep, in firmly inclosed rock basins. One of these pools situated in the ledges near the road from Rangely to the K ranch is used as a camp or watering stop by travelers if they are so fortunate as to be acquainted with its location.

ARTESIAN WELLS.

Of the wells that have been driven in the Rangely field none have encountered water in the Mancos shale, and as yet none have penetrated far enough to reach the Dakota sandstone, which is so commonly known to be a water-bearing formation under favorable conditions in other localities. It is reported that water was struck at a depth of 80 feet in the Requina oil well No. 2, which is situated close to the channel of Stinking Creek, and probably encountered an underflow of that stream. The drillers' reports state that this water was found "at the base of the adobe, in a bed of gravel overlying the shale bed rock." It is therefore assumed that the body of the Mancos shale is without water.

The possibility of obtaining artesian flow in Raven Park was suggested by White in the Hayden reports, but it now seems clear that he far underestimated the depth of the Dakota sandstone in that field. The structural conditions on which he based his estimate are apparently favorable, and such artesian flow might be available if the depth of the water-bearing stratum were not so great. Furthermore, the beds which are now seen to be the best water carriers at the springs along the foot of Blue Mountain and which occupy the most favorable positions as catchment areas on the flanks of that mountain are stratigraphically much lower than the Dakota sandstone and it would probably be impracticable to reach them by drilling from any point within the park. Although the chances that these sandstones below the Dakota may contain an artesian water supply are considered excellent, it is not at all certain that a similar flow would be found also in the Dakota beds. On the other hand, in spite of the meager catchment exposure of that formation and its apparent barrenness of springs along its outcrop it may possibly accumulate a sufficient volume of underground water to establish an artesian flow if reached by boring in the lower park lands.

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UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 351

THE CLAYS OF ARKANSAS

BY

JOHN C. BRANNER

WASHINGTON
GOVERNMENT PRINTING OFFICE
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PREFACE.

By E. C. ECKEL.

The following report on the clays of Arkansas was prepared by Prof. John C. Branner, while State geologist of Arkansas, for publication by the State Survey. The work of the organization was unexpectedly discontinued, leaving no provision for the publication of this report. Under the circumstances Professor Branner offered the manuscript for publication as a bulletin of the United States Geological Survey. As some years have elapsed since the original preparation of the manuscript, it has been necessary to bring up to date, so far as possible, the commercial and statistical data included in the report. Advantage has also been taken of recent Survey work in Arkansas to introduce later observations on the geology of certain districts. Mr. A. F. Crider has accordingly revised the sections on the geology and clay industries of the southeastern counties, while Mr. E. F. Burchard has revised the discussion of the Paleozoic clays and of certain areas in northwestern Arkansas, with a view chiefly to bringing the nomenclature into accordance with present Survey usage.

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THE CLAYS OF ARKANSAS.

By JOHN C. BRANNER.

CHAPTER I.

TOPOGRAPHY AND GEOLOGY.

GENERAL FEATURES.

The broader topographic and geologic features of Arkansas are not local and characteristic but are rather portions of several physiographic divisions which find completed expression in areas beyond the borders of the State. Nearly all that part of the State lying northwest of a line drawn diagonally across it from northeast to southwest (from Randolph County to Little River County) is comparatively elevated, and is divided by the Arkansas River valley into the Ozark Plateau (including the Boston Mountains) on the north and the Ouachita Mountain region on the south. This northwestern portion is underlain by limestones, sandstones, and shales, which are approximately horizontal in the Ozark region, broadly folded in the Arkansas Valley, and highly folded and distorted in the Ouachita Mountains.

The Ozark Plateau region north of the Boston Mountains is deeply dissected by stream erosion. Its topography is therefore rugged, but the local elevations rise to the same general level. In the Boston Mountain region, which overlooks the plateau from an irregular northward-facing escarpment 500 to 700 feet above it, the topography is largely of the terrace and escarpment type, being developed on sandstones and shales. Stream dissection has made this area also very rough and broken.

The Arkansas Valley represents a worn-down plain. Low residual hills and ridges rise above it, and its streams flow in valleys cut below the general level.

Studies of the Ouachita Mountains by J. A. Taff[a] show that the uplift of this range involves a thickness of nearly 5 miles of rock.

[a] Taff, J. A., Structural features of the Ouachita Mountain Range in Indian Territory: Science, new ser., vol. 11, No. 266, Feb. 2, 1900, pp. 187–188.

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The structure is Appalachian, and the massive sandstone and novaculite ridges, primarily arched by folding and compression, have become accentuated by the more rapid weathering of the upturned edges of interstratified shales until great contrasts of relief have resulted. The anticlinal ridges of the Ouachitas trend nearly east and west, are roughly parallel, and rise 500 to 1,000 feet above the intervening valleys, or to altitudes of 1,600 to 2,100 feet.

Bordering the plateau region on the southeast and extending eastward beyond the borders of the State across the Mississippi Valley and southward to the Gulf of Mexico is a lower belt, underlain by younger, softer strata of marls, chalks, clays, sands, and gravels. Low altitude and slight topographic relief characterize this portion of the Gulf Plains. Crowleys Ridge, in the northeastern part of the State, is a remnant of a once extensive plain that stood at a level slightly higher than the present ridge. The slope of the whole is gulfward, and the plain is trenched by many broad, shallow valleys bordered by terraces with steep escarpments.

The older rocks are of Paleozoic age, ranging from early Ordovician sediments, through the Silurian and Devonian, to those of the later Pennsylvanian epoch of the Carboniferous period. The newer deposits represent interrupted sedimentation, beginning with the early Cretaceous and including Tertiary and Quaternary deposits.

Besides the sedimentary deposits certain small areas of intrusive rocks occur at Fourche Mountain, south of Little Rock, and at Magnet Cove, near Hot Springs. These rocks have been studied and described by the late J. Francis Williams,[a] and the areas near Little Rock which contain bauxite have been described by the writer,[b] but were afterward remapped by C. W. Hayes.[c] These rocks consist mainly of elæolite syenite, popularly termed granite, and were intruded into the sedimentary rocks probably late in Cretaceous time.

ORDOVICIAN SYSTEM.

The Ordovician beds are the oldest sedimentary rocks certainly recognized in Arkansas. They consist of a thick series of magnesian limestones, sandstones, siliceous limestones, and cherts, and cover all or portions of the following counties in northern Arkansas: Randolph, Lawrence (western half), Independence (northern part), Sharp, Fulton, Izard, Stone (northeastern part), Baxter, Marion, Boone, Searcy (northeastern part), Newton (northern part), Carroll (northwestern part), and small portions of Benton and Washington.

[a] Williams, J. Francis, The igneous rocks of Arkansas: Ann. Rept. Geol. Survey Arkansas for 1890, vol. 2, 1891.

[b] Branner, J. C., The bauxite deposits of Arkansas: Jour. Geology, vol. 5, 1897, pp. 263-289.

[c] Hayes, C. W., The Arkansas bauxite deposits: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1901, pp. 440, 446, and 454.

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These rocks are, for the most part, nearly horizontal, but show gentle folds at some places, while at others they are somewhat faulted.

Ordovician rocks appear also in an area south of the Arkansas River Valley, in the Ouachita Mountain country. In this region they include the novaculites and the rocks immediately underlying them. They are exposed in portions of Pulaski, Saline, Garland, Hot Spring, Montgomery, Polk, and Pike counties.[a]

The Ouachita Ordovician rocks are composed chiefly of novaculites and shales. They have been pressed together from the north and south, so that the beds have been thrown into a series of sharp east-west folds. After they were folded erosion cut away the tops of the arches, leaving the hard novaculites as prominent ridges over the whole area.

SILURIAN SYSTEM.

Silurian rocks are known only in the northern part of the State. They rest conformably on beds of Ordovician age, but have been recognized at only a few places—in the region just west of Batesville and at points as far west as St. Joe, in Searcy County. These Silurian beds are limestones, at some places overlying a bed of shale of probable Ordovician age. The areas of these beds are too small to be represented on the accompanying map (Pl. I), so they have been included with the Ordovician.

DEVONIAN SYSTEM.

The Devonian period is represented by beds of variable character—in some places a black shale, in others a sandstone containing phosphate nodules. The thickness of the shale ranges from a few inches to 70 feet; that of the sandstone ranges from 5 to 75 feet. These rocks are known only in northern Arkansas, where they follow the contact between the Silurian and Carboniferous rocks from near Batesville westward to the vicinity of St. Joe, in Searcy County. They have been recognized also along White River northeast of Fayetteville, and in the northwest corner of the State, at Sulphur Springs, where both shale and sandstone are well developed. Although the phosphatic nodules occur sparingly in places in the lower few inches of the overlying basal Mississippian limestones, there was probably a break in sedimentation between the two formations, and the nodules have been reworked into the younger beds from the débris of the older. This formation also is so limited that it is mapped with the Ordovician rocks.

[a] A report on this area by L. S. Griswold appears in Ann. Rept. Geol. Survey Arkansas for 1890, vol. 3, 1891.

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CARBONIFEROUS SYSTEM.

MISSISSIPPIAN SERIES.

Several divisions of the Mississippian rocks have been recognized in Arkansas. Brief mention is made of each of these owing to the important bearing which the limestones and shales have on the production of clays and, consequently, the necessity for guidance in identifying the formations and in determining their areal distribution.

Boone formation.—The Boone formation consists in the main of a series of cherty limestones and cherts that has been known as the "Boone chert," a name given to the series on account of its wide distribution in Boone County. Below these over a large area in the northern part of the State lies the St. Joe limestone member of the formation, a well-marked bed of gray or pink crystalline limestone, which is the basal Carboniferous bed. It is easily recognized by its color, texture, and its marked contrast with the beds that usually underlie it. This limestone forms an almost unbroken outcrop from the vicinity of Mountain View, in Stone County, to the State line near Seligman, Mo. Where the cherts contain much limestone they form, on decay, a very fertile soil. The fine farms of Boone County about Harrison, Valley Springs, Belfonte, and Rally Hill are on the "Boone chert." This formation covers the greater part of Benton County and the northern and western parts of Washington County. Where the chert is comparatively free from limestone beds the soil is too meager for agriculture and forms the "flint hills" of western Carroll and northern Madison counties and the watersheds north of Marshall and southwest of Rush Creek, in Marion County, and the hilltops about Elixir Springs, Boone County, and Doddsville, Marion County.

Moorefield shale.—In the vicinity of Batesville there is a bed of shale lying on the Boone formation. It is well exposed around Moorefield, from which place it is named. In that locality it has a thickness of from 50 to 75 feet. To the west, at Marshall, it is not over 35 feet thick, and evidently it does not extend much farther westward. The shale has a light grayish or bluish color and is very friable. In places it is sandy. It is not important, but is described here in order to give the full sequence of rocks in the section along the northern border of the Boston Mountains.

Batesville sandstone.—Next above the Moorefield shale is the Batesville sandstone, so named from the town of Batesville, which is built on this sandstone. It is present along the base of the slopes of the isolated hills and mountains north of the Boston escarpment, in Independence, Stone, Searcy, Newton, Boone, Carroll, Madison, Washington, and Benton counties. The rock is coarse, cream-colored to brown, often false bedded, and in some places contains beds of

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shale interstratified with sandstone. A light sandy soil results from its disintegration. It serves as an excellent reservoir, for the wells that penetrate it usually find in it an abundance of good soft water.

Fayetteville formation.—Next above the Batesville sandstone lies a formation consisting principally of black or dark-gray carbonaceous shale, at many places thinly laminated. Near its base there is generally a thin bed of hard, dark gray or blue limestone, while its middle part commonly grades from a sandy shale to a true sandstone, and where the sandstone phase predominates this portion of the formation is distinguished as the Wedington sandstone member. The shale is well developed in the valley of West Fork of White River near Fayetteville, from which it is named, and the Wedington sandstone member is particularly prominent southwest of Fayetteville, in Wedington Mountain, where it attains a thickness of 150 feet—perhaps one-half the total thickness of the formation. The softness of the shale causes it to erode so easily that its outcrop is usually marked by a valley. Where exposed, the shale disintegrates readily and forms a black and fertile soil. The composition of the unweathered shale renders it suitable material for brick making. The shale beds are practically constant from the Oklahoma line to Sulphur Rock, east of Batesville.

Pitkin limestone.—Above the Fayetteville shale or the Wedington sandstone in northern Arkansas there is nearly everywhere a thin, inconspicuous bed of limestone—the Pitkin—characterized by screw-like stems of the fossil bryozoan *Archimedes*. This formation is regarded as the highest in the Mississippian series.

PENNSYLVANIAN SERIES.

Morrow formation.—Under the name Morrow formation are included several beds of limestone, sandstone, and shale which vary much in thickness, arrangement, and character, and are of but little topographic prominence. These beds lie just below the sandstone of the "Millstone grit" series of the Arkansas Survey, and, as a rule, form the middle part of the escarpment of the Boston Mountain range. South of Batesville, near Jamestown, these beds have a total thickness of about 200 feet, while in a section in the north face of the mountains, south of Fayetteville, they are about 400 feet thick. The soil derived from them is highly fertile, but the land, being for the most part very precipitous, is so badly located for agricultural purposes that it is not generally cultivated. It possesses, however, a fine timber growth and several available limestone beds.

Winslow formation.—The Winslow formation lies upon the Morrow formation and makes the summit and southern slopes of the Boston Mountains, except in the deeper ravines where older rocks have been

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exposed. Rocks of this formation also occur on the tops of the outliers immediately north of the Boston Mountains.

The formation consists of beds of sandstone and shale, with a few thin local layers of limestone. The sandstone beds range in thickness from 3 feet to more than 50 feet. One of these beds, and in places two, near the base of the formation, are conglomeratic, containing waterworn quartz pebbles of small size. These gritty beds at and near the base of the Winslow formation were described by the Arkansas Geological Survey in the report on Washington County as the "Millstone grit." The shales, which constitute probably 75 per cent of the formation, are as a rule black and carbonaceous, though less so than the shales of the Morrow formation. Coal occurs within this formation but only in beds too thin to be profitably worked. The Winslow formation in the Boston Mountain region extends up to the base of the series of rocks that contain the workable coal beds in the Arkansas coal field, and its total thickness is estimated to be more than 1,500 feet.

South of the Boston Mountains the Winslow formation is represented in a part of the thick series of sandstones and shales that underlie the coal-bearing rocks in the Arkansas coal field. This series of rocks was referred to in the publications of the Arkansas Survey as the "Lower or Barren Coal Measures." The uppermost formation in this series has been described in the report of the Arkansas coal field [a] and in publications on the Indian Territory coal field as the Atoka formation. This formation in Oklahoma and Arkansas ranges in thickness from 3,000 to probably 5,000 feet. Beneath the Atoka formation there are other formations of sandstone and shale of probable Pennsylvanian age, aggregating 12,000 to 15,000 feet in thickness.[b] These rocks make the rugged country of the Ouachita Mountain region south of the Arkansas coal field, and the Arkansas River Valley east of the coal field and south of the Boston Mountains.

In the study of the fire clays and clay shales of the State the shale beds of the "Lower or Barren Coal Measures," as well as of similar beds in the productive coal-bearing rocks, are of much importance. In the region of the Boston Mountains and in the lower region of similar formation on the east the rocks of the "Lower Coal Measures" lie flat, or approximately so, and their outcrops and distribution are thus very simple and are easily traced. In the region south of this area of horizontal beds, however, the same rocks are thrown into folds that become more and more abrupt toward the south. The upper portions of these folds are worn away by erosion, and the sandstones are left as ridges while the soft beds of shale are degraded.

[a] Bull. U. S. Geol. Survey No. 326, 1907.

[b] Branner, J. C., Thickness of the Paleozoic sediments in Arkansas: Am. Jour. Sci., 4th ser., vol. 2, 1896, pp. 229–236.

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The soil derived from the rocks of the "Lower Coal Measures," being deficient in lime and in some places rather thin, is only moderately fertile.

Hartshorne sandstone.—The Hartshorne sandstone lies at the base of the productive coal-bearing rocks of the Arkansas coal field. It is known to have a great areal extent, and is found cropping out around the edges of the coal-bearing rocks from the east end of the Arkansas coal field westward into Oklahoma. It is 100 to 300 feet thick, and contains minor beds of shale in its central and upper parts.

McAlester group.—Above the Hartshorne sandstone there is in the productive coal-bearing rocks a series of shales and sandstones with a number of beds of workable coal. The McAlester group is divisible into three formations—(1) a lower, known as the Spadra shale, consisting of three or more beds of coal and minor strata of sandstone; (2) a middle, called the Fort Smith formation, composed chiefly of sandstone and shaly sandstone beds with one or more workable beds of coal; (3) an upper, described as the Paris shale, consisting partly of beds of sandy shale with some sandstone and one or more workable beds of coal. These formations of the McAlester group are

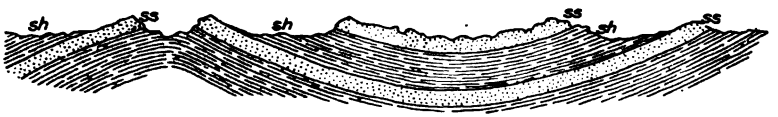

FIG. 1.—Ideal section across folds in the Carboniferous rocks of western Arkansas. *sh*, Shale; *ss*, sandstone.

described in the report on the Arkansas coal field.[a] The Spadra shale is 400 to 500 feet thick, the Fort Smith formation 375 to 425 feet, and the Paris shale 600 to 700 feet.

Savanna formation.—Overlying the McAlester group there is in the productive coal series a formation consisting of several sandstone members separated by shales. This is known as the Savanna formation. It occurs in Arkansas only in the tops and upper slopes of Poteau, Sugarloaf, Short, and Magazine mountains. That part of the Savanna exposed in Arkansas is estimated not to exceed 1,000 feet, and constitutes approximately the lower two-thirds of the formation.

The rocks of this formation, as well as the other rocks of the productive coal series, are all more or less folded, so that the shale outcrops depend on the character and direction of these folds and can therefore be determined only after a study of the structure of the region. It can be said, however, that the shale outcrops generally lie in the valleys parallel to the ridges, so that a cross section of the region would show the rocks to have the relations shown in fig. 1.

[a] Bull. U. S. Geol. Survey No. 326, 1907.

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OCCURRENCES PRECEDING THE CRETACEOUS.

Deposition of the rocks from the Ordovician beds to those of the Pennsylvanian took place over the same general area. The exposures of the Mississippian and the rocks below that horizon have resulted from the erosion or removal of rocks that once overlay them. Had the entire area of the State continued submerged during Mesozoic time, Triassic, Jurassic, and Cretaceous rocks would most probably be found to overlie the Carboniferous formations. The distribution of the Cretaceous rocks, however, shows that at the close of Carboniferous time a large area became dry land, and that the shore of the Cretaceous ocean crossed the southwestern part of the State somewhere below the northern border of the Cretaceous area shown on the geologic map (Pl. I).

CRETACEOUS SYSTEM.

Rocks of Cretaceous age occur in but a small portion of the State. They are present, concealed in some places by later deposits, in a roughly triangular area south of the Ouachita Mountains and west of Arkadelphia. The Tertiary-Cretaceous border lies slightly southeast of the St. Louis, Iron Mountain and Southern Railway between Arkadelphia and Texarkana. The rocks are not folded or bent, but dip to the southeast at a low angle. They are usually unconsolidated, contain considerable calcium carbonate, and form, on decay, a very fertile black soil. The Cretaceous deposits have been described in detail,[a] so that they need not be further mentioned here, except to call attention to the fact that later observations have shown that the Arkadelphia shale at Arkadelphia is Cretaceous and not Tertiary, as was originally supposed. Cretaceous rocks have also been recognized at a few places north of Little Rock.

TERTIARY SYSTEM.[b]

Clays, sands, and gravels of Tertiary age cover the greater part of eastern and southern Arkansas. In the rocks of this age and near their base, at Benton and near Malvern, there are valuable beds of potter's clays. These beds dip gently to the southeast. They are all more or less sandy, and but few of them are hard and consolidated. At the lignite mines of Ouachita County, however, some of the sands are indurated to very compact sandstones, and at some places in Crowleys Ridge they form the hardest of quartzites. Though the

[a] Hill, R. T., Ann. Rept. Geol. Survey Arkansas for 1888, vol. 2, pp. 66-174; also Taff, J. A., The chalk of southwestern Arkansas: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1901, pp. 687-742; Branner, J. C., The cement materials of southwest Arkansas: Trans. Am. Inst. Min. Eng., vol. 27, 1898, pp. 42-63.

[b] For details of the Tertiary geology of the State see The Tertiary geology of southern Arkansas, by G. D. Harris: Ann. Rept. Geol. Survey Arkansas for 1892, vol. 2, 1894.

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Tertiary is widespread in the eastern and southern parts of the State, it is at many places overlain by a thin coating of Quaternary deposits, so that the true character of the Tertiary beds is more or less obscured.

The lignites exposed along Saline and Ouachita rivers, the marls exposed at White Bluff and Red Bluff on Arkansas River, and the shell marl on Little Crow Creek, St. Francis County, are all Tertiary. The hard sandstones in Crowleys Ridge about Gainesville are of the same age.[a]

QUATERNARY SYSTEM.

A thin sheet of sedimentary materials, consisting of sands, clays, and gravels, cover the Tertiary area of the State and some of the adjacent Paleozoic rocks. The country lying north of Arkansas River and east of the Paleozoic hills belongs to the Quaternary. The lowest strata exposed in Crowleys Ridge belong to the Eocene. All the river bottoms are of recent origin, while the loess capping Crowleys Ridge and likewise the river terraces and second bottoms of all the important streams belong to the Pleistocene. The waterworn materials that cover the foothills of Lawrence, Independence, Pulaski, Saline, Hot Springs, Clark, Pike, Howard, and Sevier counties are of late Tertiary or Pleistocene age.

[a] Call, R. E., The geology of Crowleys Ridge: Ann. Rept. Geol. Survey Arkansas for 1889, vol. 2, 1891.

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CHAPTER II.

CHARACTER, ORIGIN, OCCURRENCE, AND USES OF ARKANSAS CLAYS.[a]

CLASSIFICATION OF THE CLAYS.

No sharply defined classification of the common clays is altogether satisfactory, for clay is not a definite compound nor a well-defined mineral species, and the qualities and values of clays depend upon physical and chemical properties which vary within wide limits, so that the various kinds of clay grade imperceptibly into one another. The clays of this State may be classified, however, with reference to their mode of formation, as: (1) Residual clays, (2) clays of mechanical origin, (3) clays and kaolins of chemical origin, and (4) bauxite. They will be briefly discussed in this order.

RESIDUAL CLAYS.

Clays and kaolins are chiefly secondary products derived either directly or indirectly from feldspathic rocks—that is, from rocks composed either entirely or largely of the mineral feldspar, such as granite, syenite, and gneiss. The feldspathic rocks may be either eruptives—that is, rocks injected in a molten condition from below into or through crevices in the earth's crust—or they may be the crystalline rocks that underlie our oldest sedimentary rocks. Whenever and wherever these rocks occur near the surface they decay—many of them very slowly—and form kaolins or clays containing more or less impurities. When the rocks contain little else than feldspar, or when the minerals that would stain or otherwise injure kaolin are removed in solution, they form, on decomposition, kaolin of more or less value; but when they contain considerable quantities of iron, manganese, or other discoloring impurities they form clays of various colors. Such clays and kaolins are said to be derived directly from feldspathic rocks.

The precise process of the alteration of the solid syenites of the Fourche Mountain region to kaolins and clays is illustrated by the following analysis. The column marked "blue syenite" shows the composition of the original unaltered rock, the column marked "decom-

[a] Persons wishing to consult other works on clays will find a bibliography of the subject in Bull. U. S. Geol. Survey No. 143, 1896; a second edition of that bibliography was published by the American Ceramic Society at Columbus, Ohio, in 1906.

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posed blue syenite" shows the chemical alteration of this same rock in process of decomposition, while the column headed "kaolin" shows the last stage of alteration to kaolin.

Analyses of pulaskite (blue syenite) and its decomposition products.

[Brackett & Smith, analysts.]

Constituents.	Blue syenite.	Decomposed blue syenite.	Kaolin.
Silica (SiO_2)	60.03	50.65	46.27
Titanium (TiO_2)		.06	
Alumina (Al_2O_3)	20.76	26.71	38.57
Ferric iron (Fe_2O_3)	4.01	4.87	1.36
Ferrous iron (FeO)	.75		
Lime (CaO)	2.62	.62	.34
Magnesia (MgO)	.80	.21	.25
Manganese (MnO)	Trace.		
Potash (K_2O)	5.48	1.91	.23
Soda (Na_2O)	5.96	.62	.37
Phosphorus (P_2O_5)	.07		
Water (H_2O)	.59	8.68	13.61
	101.07	94.33	101.00

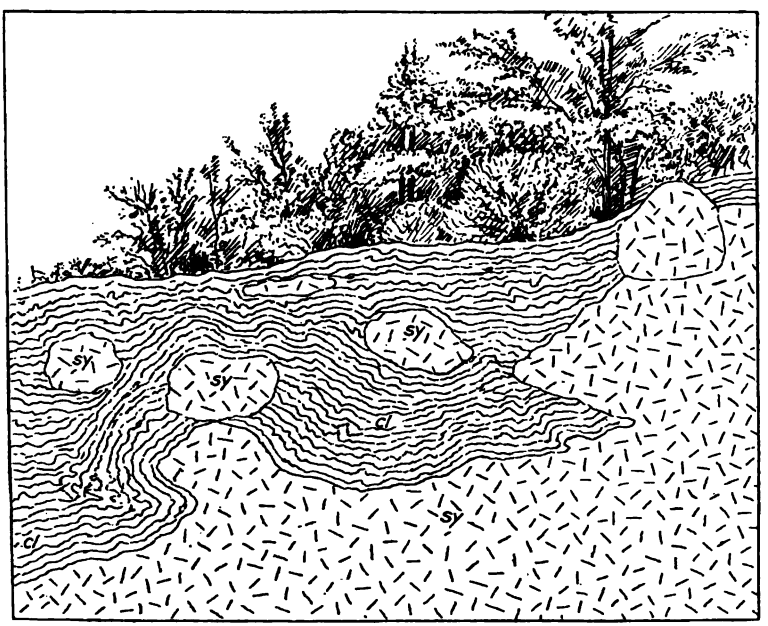

FIG. 2.—Residuary clay formed by decomposition of syenite in place, in railway cut 3 miles south of Little Rock. *sy*, Syenite; *cl*, clay.

It should be noted that the changes in passing from syenite to kaolin consist chiefly in the absorption of water, the removal of the more soluble materials, such as lime, potash, and soda, and the consequent increase of the percentage of alumina.

This blue syenite is at many places traversed by cracks or joints that break it into great angular fragments. Water charged with

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organic acids which are derived from decaying vegetable or other organic matter, on penetrating these cracks causes the rock to decay, the decomposition processes attacking the masses at first along these openings and then extending inward until only a rounded bowlder is left; later still the whole mass is converted into clay, the soluble parts of the rock having been washed out by the percolating water. Vast quantities of clays are formed in this way by the decay of the crystalline rocks, and no doubt such decay has been going on since the crust of the earth began to harden.

Fig. 2, sketched in the railway cut 3 miles south of Little Rock, illustrates this method of forming clay, the clays at that place having been derived directly from the syenites by decomposition.

Bruno Kerl[a] holds that feldspar may even be decomposed by water alone at high temperatures and under strong pressure, yielding

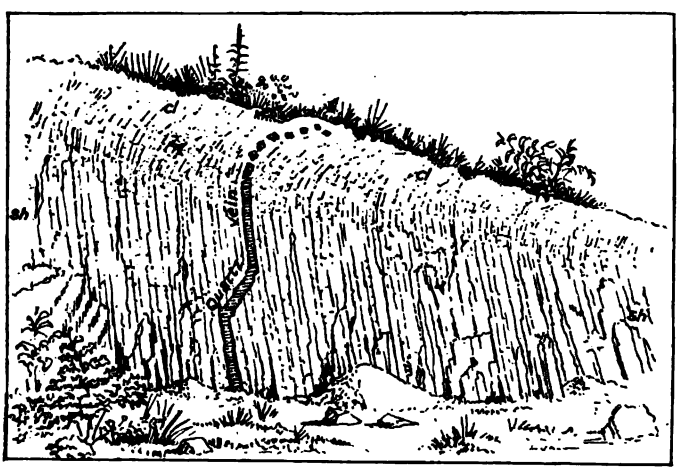

FIG. 3.—Shales decaying at the surface in railway cut at Little Rock. *sh*, Shale; *cl*, clay formed by decomposition of shale in place.

clay, silicate of potash, and silicic acid. Carbonic acid may produce similar decomposition at ordinary temperatures and without pressure.

Fig. 3 is a sketch made in the railway cut about a mile west of the union depot at Little Rock. The clays at the top of the ground here are simply the decayed upturned edges of the shales exposed in the railway cut. Deeper down the shales are compact and undecomposed.

The thin vein of quartz in the shale evidently once passed upward into the extension of the shales, but as the shales decayed and formed a soft clay the quartz, not being so readily attacked by weathering agents, simply broke into irregular fragments and remained in the clay or shale after it was decomposed. Any other insoluble materials in the shale, such as sand, would thus be left as an impurity or grit in the clay.

[a] Handbuch der gesammten Thonwaarenindustrie, Braunschweig, 1879, p. 29.

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The clay in this place is derived directly from the shale. But the shale itself is an argillaceous rock which was originally made from clays and sediments that washed down from land where some of the old feldspathic rocks were decaying or had decayed. This residuary clay is thus derived directly from shale, but indirectly from feldspathic rocks.

Fig. 4 shows the derivation of clay from limestone by decomposition, the lime of the rock being dissolved out and carried away, the clay, iron, sand, and whatever insoluble impurities the rock contained being left behind. This clay is of a deep red color. It contains some fragments of the limestone from which it is derived—small pieces not yet completely decomposed. This limestone contains nodular pieces of chert or flint, and as these do not decay, or at least do not decay so rapidly as the limestone, they are left as loose pieces in the clay. The clay in this case comes from the impurities

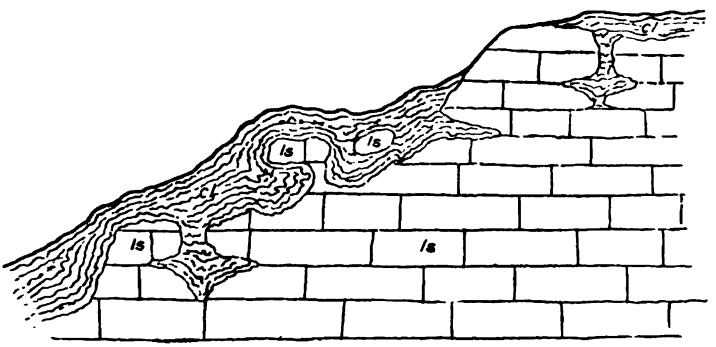

FIG. 4.—Section on Dry Creek, Carroll County, showing formation of clay by decomposition of limestone. *ls*, Limestone; *cl*, clay.

in the limestone, and these impurities, in so far as they form clay, were deposited as an argillaceous silt with the calcareous material that forms the limestone. This will serve to explain at once the origin of the clays of some limestone regions and the great blanket of clay found over most limestone regions, as well as that found in caves and in crevices and fissures in limestones.

Clays thus formed and lying where they originated are the residue from the decay of some hard rock, and are therefore called residuary clays. Other illustrations might be given to show how clays are derived from other kinds of rocks than those mentioned, but these are enough to show what is meant by residuary clays. The decomposition of rocks and the formation of residuary clays may be seen in almost every part of the elevated portion of the State.

It is evident that the clays derived from any of the rocks mentioned must vary more or less among themselves, according to the amount and character of the insoluble contents of the rocks from

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which they are derived. Wherever these residuary clays are exposed at the surface they are usually still further modified by weathering and by organic agencies. When they are washed into streams, sorted by the currents, and deposited again they form what are known as redeposited clays.

CLAYS OF MECHANICAL ORIGIN.

Clays may be produced by grinding to a fine powder any rock that will produce clay upon decomposition. When thus pulverized some of these rocks, possibly all of them, become more highly hydrated or take up more water of crystallization,[a] a change which is probably explicable, in part at least, upon the theory that much more rapid decomposition is produced by finely dividing the material so as to expose a very large surface to decomposing agencies. The trituration of rock fragments dashed against one another either by the current of a stream or by the action of waves wears the fragments round, forming cobblestones, pebbles, sand, and mud. More mud than sand is formed in this operation—in other words, the greater part of the material passes almost directly from the condition of a solid rock to that of a clay. This clay is carried along by the water until the current is checked, when it gradually sinks to the bottom and forms a bed or layer. But whether the argillaceous sediments carried into the sea by streams are of mechanical or chemical origin, they all go to form new beds of clays over the bottom of the sea. All parts of the earth's surface above the ocean's level are being gradually cut down by the slow but never-ceasing processes of weathering and erosion and are carried away either in chemical solution or in mechanical suspension. In this process of degradation the heavier materials are left behind for further disintegration, while the lighter—that is, the clays and fine sands—are carried away by streams. This mechanical separation by water goes on constantly, and during the eons of geologic time the results of such agencies have accumulated until they have ultimately produced an impressive and almost incredible total.

KAOLIN.

The distinction between clay and kaolin, except in a mineralogical sense, is an arbitrary one, for the two grade imperceptibly into each other. Both kaolin and clay are derived chiefly, either directly or indirectly, from feldspathic rocks by decomposition. Kaolin is composed of silica, alumina, and water, usually with a little impurity, while clay has the same constituents, but its impurities form a larger percentage of its composition. These impurities are often in the

[a] Daubrée, A., Géologie expérimentale, p. 252.

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form of free silica or fragmentary quartz, and this being anhydrous an analysis of the material shows a smaller percentage of water than is found in the purer clay or kaolin. Thus, while kaolin usually contains about 12 per cent of water, the clays have less than 8 per cent.[a]

Kaolin deposits may originate in three ways—(1) by the alteration of feldspar in place; (2) by chemical action other than the ordinary alteration of feldspar, as illustrated by rectorite; (3) by the washing down and redepositing of kaolin formed in place. The great bulk of our kaolins, however, are derived directly from feldspar. The process by which feldspar or feldspathic rocks are changed to kaolin is kaolinization. Syenite, which is generally known in Arkansas as "granite," is made up largely of feldspar, and when the feldspar decomposes, as it always does sooner or later, it forms kaolin. The other ingredients of the syenite, however, such as hornblende, mica, iron, pyrites, and quartz, remain in the residuary material, so that it does not form pure, clean kaolin, but is generally an impure clay. Below are analyses of feldspar, of a variety of Arkansas syenite, and of a syenite partly changed into clay.

Analyses of feldspar, syenite, and kaolin.

	Feldspar.[a]	Blue syenite.[a]	Decomposed syenite.[b]	Kaolin.[c]
Silica (SiO_2)	66.39	60.03	58.50	46.27
Alumina (Al_2O_3)	18.13	20.76	25.71	38.57
Ferric oxide (Fe_2O_3)	1.44	4.01	3.74	1.36
Ferrous oxide (FeO)	.....	.75	.....	.....
Lime (CaO)	.16	2.62	.44	.34
Magnesia (MgO)	.06	.80	Trace.	.25
Potassium (K_2O)	8.51	4.48	1.96	.23
Soda (Na_2O)	5.36	5.96	1.37	.37
Phosphoric acid (P_2O_5)	.....	.07	.....	.....
Water	.42	.59	5.85	13.61
	100.47	101.07	97.57	101.00

[a] From Fourche Mountain, Little Rock, Ark.
[b] From Pulaski County, railway cut 2 miles north of Sweet Home.
[c] From sec. 9, T. 1 S., R. 12 W.

These analyses show that in passing through the process of decomposition from a hard blue syenite to a kaolin the rock loses part of all its ingredients except alumina and water, which are proportionately increased; or perhaps it would be better to say that the removal in solution of some of the constituents leaves others predominant. The change from feldspar to kaolin goes still further, but the feldspar contains less iron and is therefore more liable to end in a clean white kaolin than is the ordinary rock.

[a] Of course no reference is here intended to prophyllite or rectorite, which are hydrous silicates of alumina and contain less than 8 per cent of water. Those substances, however, are not likely to be mistaken for common clays.

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POTTERY CLAYS.

By pottery clays is here meant such as are commonly used in the manufacture of crocks, jars, jugs, and churns at the potteries now in operation, and not the poorer kaolins that might be used for similar purposes. All the clays of the State that are or have been used for the manufacture of pottery are grouped here under the head of pottery clays, whether or not they are available for other and more important uses. The common pottery clays of Pulaski, Hot Spring, Saline, Clark, Hempstead, and Miller counties, and those in other of the southeastern and eastern counties of the State, are all of sedimentary origin and of Eocene or lower Tertiary age. They were laid down in nearly horizontal beds, which generally dip toward the southeast at a low angle, so that beds that outcrop at or near the Paleozoic highlands lie at depths that become greater toward the southeast. In nature these Tertiary deposits vary from coarse sands through earthy marls to fine plastic clays. Many of the clay beds contain impressions of fossil leaves and small sticks of wood—materials that evidently sank, with the clays that inclose them, to the bottoms of the swamps or lagoons that once covered this region.

While the pottery clays dip to the southeast and gradually descend to greater depths beneath the surface, the beds do not preserve throughout the characters they may display at a single exposure. It is a well-known fact in geology that sedimentary beds may vary in character and thickness from one point to another; indeed, they are even more liable to vary than to be constant in thickness and character. So while the pottery clays may be of uniform thickness and quality toward the southeast, or may even improve in quality and increase in quantity, it must not be inferred that this is proved. It is possible that they form lenticular masses; but in any case, those who would prospect for pottery clays within the Tertiary area of the State would do well to bear in mind their structural features and their possible variations.

Although sediments are deposited in approximately horizontal beds, the pottery clays about Benton and elsewhere in the Tertiary region of the State occur as fragmentary beds in isolated hills. After the Tertiary beds had been laid down they were elevated, so that from being soft muds and sands at the bottom of the sea or of lagoons they came to form "dry land." But all "dry land," or all of the crust of the earth that stands uncovered by water, is subjected to eroding agencies which cut it down and wash it away, leaving its surface scored and furrowed by gullies, ravines, and valleys. By this process the beds of former sediments are carried away, whether they be sands, gravels, or clays, while over the surface is spread out a thin covering of the less soluble or less portable material.

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CLAYS FOR DRAIN TILES.

There is no lack of clay in this State available for the manufacture of good drain tiles. The light-blue clays through the country lying between Beebe and Kensett and thence to Judsonia, and between Kensett and West Point, in White County, are available for the manufacture of tiles. The clays about Brinkley, Monroe County, are well adapted to tile making. Along the western base of Crowleys Ridge in Phillips, Lee, and St. Francis counties, and on both sides of the ridge in Cross, Poinsett, Craighead, Greene, and Clay counties, these clays are abundant and of excellent quality. They abound also along Bradshaw and Terre Noir creeks in Clark County.

In the counties south and southeast of Little Rock clays available for tile making occur both as surface soils in the valleys (not alluvial) and in the widespread stratified Tertiary beds of the region.

In the hilly regions north of the Cretaceous and Tertiary area of the State drain tiles are not likely to come into demand except, perhaps, in the bottom lands, but wherever they may be wanted they can be made from the brick clays that have accumulated in the valleys.

Along the Petit Jean and Fourche le Fevre the surface soils of the lowlands are generally available for tiles. In the neighborhood of Arkansas River tile-making material may be found in abundance in the terraces of brown and reddish clays that lie just outside of the "second bottoms." Any of these clays will be improved for tile making if they are allowed to weather through a winter.

The demand for drain tiles has hitherto been so limited that but little work has been done in manufacturing them. Whatever benefits may come from the drainage of the soil are either unknown to the average landowner or are disregarded, while the expense of procuring tiling and draining has acted as an additional drawback to the custom of underdraining in places where it would be of great service. There can be no doubt, however, that many of the most fertile lands of the State of Arkansas that now lie unused could be brought under cultivation if they were only properly drained. The custom of underdraining must necessarily be adopted by our farmers in the near future, and when fairly tried it will soon prove its own importance on certain kinds of lands. It is especially true of the lowlands within the Quaternary area of the State. R. E. Call, who has paid especial attention to the Crowleys Ridge region, is of the opinion that thousands of square miles that now lie idle along White, Cache, L'Anguille, and Arkansas rivers can be brought under profitable cultivation by some system of underdraining.

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BUCKSHOT CLAYS.

Character.—In many places in this State and at some places over a great many square miles, both in the Paleozoic highlands of the western part of the State and in the Tertiary and Quaternary lowlands of the east, there is a kind of clay, usually of an ashen color, but often mottled red, gray, and yellow, that contains great quantities of nodules of iron (limonite) varying in size from that of a pin head to that of a walnut. This is one of the soils known as "buckshot" land, a name doubtless given to it on account of the size and form of these nodules.[a] The nodules at some places lie along a broad but well-defined line at a uniform depth from the surface; in others their depth varies greatly; they may be on the surface or may lie as deep as 5 or 6 feet below.

Origin of the "buckshot."—The process by which these nodules are formed seems to be as follows: The iron was originally distributed through the uppermost bed of the surface clay. Vegetation growing and decaying on the surface furnished vegetable acids to waters that penetrated the soil and dissolved out the iron from the upper portions of the beds. As the iron-charged waters penetrated the clays the iron was precipitated at points a short distance below the surface to form the buckshot nodules. These nodules are never very abundant on hillsides or steep slopes,[b] but occur for the most part on gentle slopes and in the soils of the "slashes" or flat lands on which the water stands or has stood during wet seasons. The leaching of the iron from the upper beds of clay leaves them usually of a pale ashen or cream color, while the admixture of organic matter sometimes gives them a leaden color.

Carbonic acid is probably one of the most active agents in dissolving the iron from the surface soil and redepositing it at lower depths. But on descending with water through the upper layers, so long as water stands upon the ground, carbonic acid will not give up its iron. If it should pass downward the iron would remain in solution, and if it flowed away laterally the iron would be precipitated only when the water came near the surface. It therefore seems probable that this iron remains in solution until the wet grounds become dry, when it is precipitated by the evaporation of the water. As might be expected from the conditions under which these lumps of iron are formed, they vary in size and in their distance from the surface, and the bands in which they are arranged vary in thickness.

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[a] In Arkansas another kind of soil is also known as buckshot land. The latter is calcareous alluvial soil containing considerable clay. After being plowed the clods, on weathering, break into small cuboidal lumps, which appear to have suggested the name buckshot by their size rather than by their shape. This soil is usually very fertile, while that containing the limonite nodules is rather poor.

[b] At Forrest City a band of limonite nodules is exposed in a railway cut 43 feet below the surface. This probably represents the ancient soil cited by Chamberlin and Salisbury as underlying the loess. (See Call's report on The geology of Crowleys Ridge: Ann. Rept. Geol. Survey Arkansas for 1889, vol. 2, p. 159, and Pl. I, fig. 2, p. 206.)

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Uses.—In many parts of the State these buckshot clays are used for making common bricks, but they are not very well adapted to such use. The iron lumps cause hard black spots in the bricks, and the clay is more or less troublesome to work by hand, for the nodules tear the hands of the brick molders and catch on the sides of the molds These difficulties could be averted by crushing or screening the clay, but it is doubtful whether the expense of such a process would be warranted in making ordinary bricks.

It is of much importance to find that some of these lowland clays have been used successfully in the manufacture of Portland cement at Whitecliffs, in Little River County. In reply to inquiries about the clays employed, the secretary of the company, Mr. W. J. Kelly, kindly furnished the following information.:

The first clay we used for making cement was taken from the SE. ¼ SE. ¼ sec. 35, T. 11 S:, R. 29 W., on the west side of Little River, the analysis of which is as follows:

Analysis of cement-making clay mined on Little River near Whitecliffs.

SiO_2	72.64
Al_2O_3	13.91
Fe_2O_3	3.72
CaO	.20
MgO	.45
Total volatile	7.53

As this deposit is across the river from the works, we experimented with the clays on the east side of the river and found a bed of clay one-fourth of a mile south of the plant.

The bed of clay on this side of the river is several acres in extent and 16 feet thick in the SW. ¼ SW. ¼ sec. 36, T. 11 S., R. 29 W. The analysis of this clay is as follows:

Analysis of brick clay mined on Little River near Whitecliffs.

SiO_2	74.54
Al_2O_3	14.47
Fe_2O_3	1.79
CaO	.73
MgO	.41
Total volatile	6.26

Alkalies not yet determined.

From this clay we also made 2,000,000 red brick in 1897 and 1898. There is no stripping whatever, as the deposit starts at the surface. We have a narrow-gage railroad from the plant to the pit.

THE LOESS.

The loess constitutes the upper 30 to 90 feet of the higher portions of Crowleys Ridge from Dee post-office, in Craighead County, southward to Helena, in Phillips County. At Helena it attains its maximum thickness. Throughout the areas of its distribution, both in Arkansas and in other States, it usually contains large numbers of limy concretions, or puppets, which are highly characteristic of its soils.

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Throughout the region it covers in Arkansas the loess may be readily recognized by its fineness and by its light-yellow or buff color. In certain localities it becomes slightly darker in color, possibly by reason of the presence of organic matter, or it may even be blotched with dark-brown and reddish colors. Close examination of these blotches reveals the fact that the color is due to a superficial coating of iron oxide on the individual grains.

This loess is especially suited to the manufacture of superior grades of brick. Care is necessary in its preparation for molding, however, and discrimination is required in respect to the mixture of soils from the neighboring hills. Where the soils of the hillsides are largely made up of sands and gravels derived from local outcrops of the Tertiary strata, as they are in some places about Jonesboro, Harrisburg, Gainesville, and Wynne, they are unsuited to the manufacture of good brick. At other localities, notably near Marianna, at Forrest City, and at La Grange, the slopes of the hills, along their lower margin, contain many small nodules of limonite, which render the soils less valuable for brick manufacture. If these nodules be removed by screening, the soils can be used successfully in brick manufacture. But at all these localities there are abundant deposits of clean loess that furnish unlimited opportunities for brickmaking.

The bricks made from the Crowleys Ridge loess usually burn to a good color—cherry-red for hard, and a lighter shade of red for the soft burned ones.

Near Marianna, in the SW. ¼ SW. ¼ sec. 19, T. 2 N., R. 4 E., many acres are covered by a peculiarly colored modification of the loess, which contains a higher percentage of iron oxide than the typical loess. It is a very fine homogeneous deposit and fills the lower portion of all the creeks, ravines, and gullies of the neighborhood. It will prove a superior brick clay and will burn to a rich, uniform red. It is well adapted to the manufacture of ornamental front and pressed brick.

The hilly country north of Poinsett County differs from other parts of the State in the distribution of the loess and its relations to the Tertiary strata. The loess there is found only on the slopes of the hillsides or on the low spurs of the ridge wherever they extend far from its main mass, and it is there a less prominent geologic feature than it is in the country south of Craighead County. In this hilly country its relations to the Tertiary sands and gravels are such that in most localities the loess deposits are more sandy and apparently less homogeneous; the quality of brick that may be made from this soil, while excellent, will not be so fine as that made from unmodified loess.

In Memphis, St. Louis, Des Moines, Council Bluffs, and Ottumwa, Iowa; Omaha, Nebraska City, and David City, Nebr.; St. Joseph,

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and Kansas City, Mo., and other cities where loess soils are used in brick manufacture, grinding mills are employed to reduce them to the finest powder. In this condition they are fed at once to great dry-pressing machines, from which they are immediately set in kilns. When it is treated thus, or in a similar manner, no material is better suited to brick manufacture. The processes employed in brick manufacture must be varied with the variation in the nature of the brick earth used.

SLOPE SOILS.

At all points along the ridge country, except Helena, the reworked loess is commonly employed in brick manufacture. It occurs on the sides and at the foot of the ridge. The soil is stripped a few inches, to remove the mass of vegetable matter, and the subsoil, to a depth varying from 1 to 5 feet, is used for brickmaking. The clay is thrown into pits, with water, and allowed to stand for two or three days or a week, when it is pugged. It is then molded and dried in the usual manner.

The soils and clays of the slopes present the greatest range of variation in character. They differ greatly within short distances, at places becoming very clayey, at others sandy, or even gravelly. The variation in microscopic appearance is due to the relative erosion, both of amount and rate, to which the various strata have been subjected. In many places, as at Harrisburg, in Poinsett County, and at Wynne, in Cross County, the loess soils have been largely removed by erosion, so that the underlying Tertiary sands have been exposed and the soils of the slope have become more sandy than soils of the same class about Forrest City, Marianna, La Grange, and Helena. The characters exhibited appear to differ locally, also. Where the slope is rather steep the clays and intermingled sands alike are eroded away, having been carried down to the lower lands and redeposited over the flat country as a thin surface soil or sandy loam, but in situations where the slope is less marked the clays alone are carried off, while the sands and gravels are left behind. This appears to be the explanation of the character of the soils along all that portion of the ridge country or slope north of Jonesboro, on the eastern side of the ridge. There the slope of the ridge is gentle and the conditions are favorable for the removal of the clay. But on the west slope of the ridge from Craighead County northward to the Missouri line the slope of the ridge is abrupt, and the erosive agents carry off all that is movable, whether it be sand, gravel, or clay. These are again mixed with much organic matter on the plains below and immediately adjoining the ridge, which modify the soil.

From these slope soils are manufactured most or all of the bricks produced at Paragould, Gainesville, and Jonesboro. Commonly only

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a few inches of the surface soils are stripped off and used, care being taken not to go too deep into the subsoil, which is too stiff to mold well with the processes employed, and which is, besides, but little different from the ordinary limonitic or hardpan clays of the bottoms. This soil extends out from the ridge toward the east, surmounting the low divides between the numerous drainage areas. The soils higher up in the hills contain more loess clay and less limonite, but commonly more sand.

With such marked differences in the characters of the slope soils or clay at localities very near one another, it is not surprising that the bricks produced exhibit every degree of color, finish, hardness, and durability.

CLAYS AND KAOLINS OF CHEMICAL ORIGIN.

It has been stated that kaolin was derived directly by decomposition of feldspathic rocks. While this is true in a general way, all kaolin is not made in this way. It occurs in small quantities in regions of Paleozoic rocks, where it forms thin bands or fills small pockets. In these places it seems to have been formed by chemical action. It is true that kaolin is practically insoluble, but certain forms of silica are equally insoluble, yet these very forms are soluble under certain conditions if time enough is allowed for solution. The same is doubtless true of kaolin, otherwise we should not have deposits which are far removed from the original feldspathic rocks and which can be explained by no other theory. Either kaolin is soluble in some substance or under certain conditions of which we are as yet ignorant, or it is soluble in the waters that usually traverse the rocks when plenty of time is allowed for reaction to take place.

In any case the kaolin (newtonite) found in small pockets in the rocks of the northern part of the State was not deposited as a sediment as were the shales and sandstones and limestones of that region, nor was it derived by decomposition directly from feldspathic rocks, but it is a secondary deposit, derived by chemical action from the sedimentary beds above and about it.[a] The same is true of rectorite, which occurs in Garland County.

BAUXITE.

The pisolitic clays and kaolins associated with the bauxites of Arkansas, in so far as their origin is understood, do not appear to fall under any of the foregoing classes. Their composition varies from that of an iron ore carrying 55 per cent of metallic iron to that of a true kaolin with but little or no iron. In some places they pass by gradual transition into true bauxite—that is, a hydrated oxide of

[a] See Chapter III of this report, p. 34.

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alumina; in others they are a true kaolin, a hydrous silicate of alumina. In Arkansas, as in southern France and in Ireland, where similar deposits occur, they are associated more or less intimately with eruptive rocks. They occur in pockety deposits of uncertain distribution, with a tendency to form horizontal lenticular beds varying greatly in thickness as well as in character. Their origin is involved in some obscurity.[a]

[a] The most comprehensive report on Arkansas bauxite is that of Dr. C. W. Hayes, published in Twenty-first Ann. Rept. U. S. Geol. Survey, 1899–1900, pt. 3, pp. 441–472. An earlier paper by J. C. Branner (Jour. Geology, vol. 5, 1897, pp. 263–289) contains a brief bibliography of bauxite.

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CHAPTER III.

GEOLOGIC AGE AND GEOGRAPHIC DISTRIBUTION OF THE CLAYS.

CONDITIONS GOVERNING DISTRIBUTION.

The distribution of clays depends on the distribution of the geologic formations from which they are derived, and hence on geologic structure. From what has been said of the origin of clays it will be seen that their distribution throughout the State must necessarily depend on the State's geologic history, or the manner and order in which the rocks have been made and unmade. Where we have the crystalline rocks, which yield kaolin on decay, there we may look for kaolins, and in order to look intelligently we must know the distribution of those particular rocks. The clay shales we can expect to find only in association with the Paleozoic rocks, and as they are abundant in the rocks of the Carboniferous system we must ascertain the distribution of the rocks of that age. The Tertiary and Cretaceous clays can be found only with the Tertiary and Cretaceous rocks, and in searching for them it is essential to know the areas of these rocks in the State, the position in which they lie, the character of the various beds, and the places the clays occupy in the series.

These instances are cited for the purpose of showing how indispensable to an intelligent search for clays is a knowledge of geologic structure and the areal distribution of the various geologic formations. A geologic map of the State (Pl. I) is inserted in this report for the purpose of furnishing this information.

PALEOZOIC CLAYS AND SHALES.

The clays of the Paleozoic areas of the State consist of shales of Paleozoic age found in place, and of alluvial or other clays of recent age spread over the lowlands. The clays of the latter class are derived indirectly from the Paleozoic rocks of the surrounding regions and may form brick earths or pottery clays.

When clays are subjected to a great pressure for a long time they become hard and stonelike, forming what are known as shales and slates. Nearly all of the clays of Paleozoic age have been crushed under pressure so great and for so long a time that they have become thus hardened into shales.

The clay shales which were derived from the wear and decay of other rocks were originally deposited in horizontal beds in the water of the

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ocean or of bays and swamps, and if they are now thrown into folds, raised into mountains thousands of feet above the ocean, and hardened into stone, it is only because they have been crushed till they are hard, pressed laterally into folds, and elevated until they stand high above their original positions. Subaerial erosion has subsequently removed much accompanying and surrounding material, and in places these shales have weathered into residuary clays, such as have been described on page 20.

The clays of the Paleozoic regions have values peculiarly their own, for while the clays of the Tertiary area of the State are especially well adapted to the manufacture of pottery, those of the Paleozoic regions are largely adapted to the production of fire bricks, sewer pipes, and paving bricks.

The Paleozoic rocks have furnished the greater part of the refractory material of the world. These clay and clay shales do not as a rule possess as high refractory properties as bauxite, steatite, graphite, or magnesite, but the latter are much less abundant and are for this reason much more expensive, while articles made from clays and shales are sufficiently refractory for most of the common uses for which refractory materials are employed, and the abundance and cheapness of such clays insure for them a constant and ever-increasing demand. In the United States the clays and clay shales of the Carboniferous rocks are extensively used for certain manufacturing purposes, while raw clays are shipped to points all over the country to be used for the manufacture of retorts and furnace linings of special forms.

The various zinc-smelting works in the United States make their own retorts, and the clays used for this purpose are brought to the reduction works from well-known Paleozoic beds. And it should not be forgotten in this discussion of the character and distribution and uses of the clays of this class that their value, other things being equal, is determined by their proximity to manufacturing centers and to competing lines of railway transportation. These important factors have built up the fire-clay industries of St. Louis and Cheltenham.

The St. Louis, Iron Mountain and Southern Railway extends along the eastern edge of the Paleozoic area of Arkansas north of Arkadelphia. The southern border of the Paleozoic runs nearly due west from a point on Ouachita River a few miles north of Arkadelphia.

Within this Paleozoic area the clays and clay shales are unevenly distributed. In the Ordovician region, lying north of the Boston Mountains, shales and clays of value are much less abundant than they are in the Boston Mountains and in the Carboniferous rocks farther south. Again, in the Silurian region of the great Ouachita anticline, running from near Little Rock to the Indian Territory line, in Polk County, there are many mountains of novaculite in

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which there are but few valuable beds of shale. In the great river bottoms of the Arkansas there are large tracts covered by river silts that are not available for the manufacture even of the most ordinary building bricks. However, there is not a single county in the entire Paleozoic area in which fairly good brick clays may not be found.

CRETACEOUS AND TERTIARY CLAYS.

It is only for the sake of convenience in presentation that the Cretaceous and Tertiary clays of the State are here treated in the same chapter. A glance at the geologic map of Arkansas accompanying this report (Pl. I) shows that rocks of Cretaceous age outcrop over a relatively small part of the State.[a] They are found in only about seven counties.

During Tertiary time, a period not far removed from the present, geologically, a large part of the State of Arkansas was covered by the ocean. The western shore of the Tertiary sea entered the State on the southwest somewhere in the vicinity of Ultima Thule, and passed into Missouri near the line between Clay and Fulton counties. The western margin of the Tertiary, as shown on the geologic map (Pl. I), marks approximately the old shore line. With the northern limits of this sea we are not now concerned, but on the east it extended nearly to Tennessee River, covering all of eastern Arkansas, while almost all the State of Mississippi lay beneath its waters.

All waters that flowed into this Tertiary sea carried down great quantities of sands and clays, just as to-day sands and clays are being carried out into the Gulf of Mexico by the Mississippi and by all the surface waters that flow into it. This material was spread out over the floor of the sea in beds as nearly horizontal as the nature of the bottom and the currents would permit, and with them were mingled the shells and bones of animals that lived and died in the water and the leaves and stems of plants that were floated out by the streams. Later the land was elevated until the silt of that ancient sea bottom now stands 375 feet (at Little Rock) above the present ocean's level.

During this depression of the land the Tertiary clay beds of the State were deposited, and the conditions under which these beds were formed satisfactorily account for their characters, their distribution, and their included fossils.

Should we go back a little further in geologic time we should be able to account also for the clay beds of the Cretaceous region in the southwestern corner of the State. The conditions under which they were deposited differed but little from those under which the Tertiary clays were formed. Neither the Cretaceous nor the Tertiary

[a] The Cretaceous geology of the State has been described by Prof. R. T. Hill in Ann. Rept. Geol. Survey Arkansas for 1888, vol. 2.

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clays are hard, but neither are they geologically very old, nor have they been subjected to that great pressure that has so often affected the older clay beds of the earth's crust, many of which now form shales and slates.

The Tertiary geology of Arkansas south of Arkansas River has been described in detail by Prof. Gilbert D. Harris,[a] and the Tertiary and later beds of the Crowleys Ridge region of northeastern Arkansas by Dr. R. E. Call.[b] The present report does not undertake to deal with questions of stratigraphy within the Cretaceous, Tertiary, and Quaternary areas, except in so far as they relate to the details of the clay deposits.

The general geology of the Cretaceous and Tertiary portions of the State should be fairly well understood by those who have to deal with the clays that occur in those formations. The Cretaceous beds are older than those of Tertiary age, which they underlie. They are exposed in the counties west of Arkadelphia, namely, in Clark, Nevada, Pike, Hempstead, Howard, Sevier, and Little River. Everywhere in this region they slope gently toward the southeast.

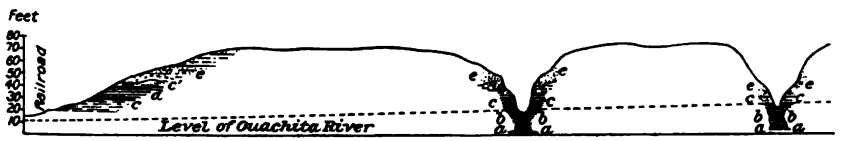

FIG. 5.—Section at Arkadelphia, Ark., extending from a point near the Baptist school southward to the Iron Mountain Railway. *a*, *b*, Sands; *c*, *c'*, Arkadelphia shale; *d*, clay; *e*, gravel.

They are made up of beds of chalk, marl, gypsum, sandstone, and clay. The clays of this group, however, are of comparatively small importance. The only extensive beds noted are the blue clays exposed near the railway in the south side of the town of Arkadelphia. These clays were originally called the Arkadelphia shale by Prof. R. T. Hill and were believed by him to belong to the Tertiary.[c] Later, however, Prof. G. D. Harris found that they belong to the Cretaceous.[d]

It is not known that the Arkadelphia shale has any economic value. It is usually so interbedded with thin laminæ of sand that it can not be used for the manufacture of pottery, but probably this same bed may elsewhere be suitable for the manufacture of pottery or available as fuller's earth. This shale bed is exposed at several places about the town of Arkadelphia and also on the upper part of Big Deciper Bluff 5 miles southwest of the town. The yellow sandy clay overlying the chalky marl on the Wright place, on Little

[a] Ann. Rept. Geol. Survey Arkansas for 1892, vol. 2.
[b] Ann. Rept. Geol. Survey Arkansas for 1889, vol. 2.
[c] Ann. Rept. Geol. Survey Arkansas for 1888, vol. 2.
[d] Ann. Rept. Geol. Survey Arkansas for 1892, vol. 2, pp. 15–19.

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Deciper Creek, seems to be the same shale bed. Professor Harris has identified the Arkadelphia blue shale again on Mine Creek, near the old town of Nashville, where it is 4 feet thick.[a]

Within the Cretaceous area there are large areas covered with buckshot clays. These clays are not of Cretaceous age, but are much newer—Pleistocene and Recent—and are made of the residue of any clay-bearing strata that may be at hand after the decomposition of the underlying rocks. In the low, flat lands, commonly known as "slashes," thin beds of plastic clays are found at places where acidulated waters have leached the iron from the soil. Some small potteries get their clays from such places. The supply of available clays of this kind is uncertain, and most of the areas covered by them are small. Such clays occur in the flat lands of the Cretaceous, Tertiary, and Quaternary areas of the State, which, however, are not alluvial lands, properly speaking.

Reference has been made to the waterworn materials that occur in the Tertiary region of southern Arkansas. This material is at some places extremely coarse, made up of cobbles the size of a man's head or even larger, and at others consists of pebbles no larger than a hickory nut. This gravel spreads over and obscures the outcrops of the Tertiary beds throughout the region, and is especially thick along the foothills on the northwestern margin of the Tertiary exposures. In thickness the deposit varies greatly, being in one place only a few inches and in another from 25 to 40 feet thick. In some places it has a tendency to accumulate in depressions; in others it is found in considerable quantity only on the hilltops. Inasmuch as the presence of this waterworn material often interferes not a little with prospecting for pottery clays these peculiarities of its distribution should be kept in mind by prospectors and clay miners.

The presence in the pottery clays of leaf impressions has been mentioned. A small collection of these was made and sent to Lester F. Ward, of the United States Geological Survey, for the purpose of ascertaining whether they threw any light upon the geologic age of these clays. Professor Ward's conclusions on this subject are that the beds are probably lower Tertiary, but he says that the specimens from the Henderson clay pit, north of Benton, Saline County, "have a very curious and suggestive resemblance to some of the Amboy clay leaves, and I strongly suspect that you have gotten into the Cretaceous."

It is interesting to know that the fossil leaf impressions from these clays are probably all of new species, but the fact that they are new, as Professor Ward remarks, decreases their diagnostic value in determining the age of the deposits. The age of the pottery clays could not therefore, without more collecting at least, be decided

[a] Ann. Rept. Geol. Survey Arkansas for 1892, vol. 2, pp. 20-21.

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by the fossil plants peculiar to the beds themselves. Marine fossils of Eocene age have been found east of the outcrops of the clays, however, at Warren, in Bradley County; at Monticello, in Drew County; at Rison, Kingsland, and about New Edinburgh, in Cleveland County; and at White and Red Bluffs, on Arkansas River, in Jefferson County. The pottery clay beds of Saline and Hot Spring counties seem to dip beneath the fossil-bearing beds mentioned above, and must therefore be not later than Eocene. For these reasons these beds are spoken of in this respect as being of Tertiary age.

With this understanding of the general characters, age, and origin of the common Tertiary pottery clays of the State we may take up the details of their occurrence.

The Tertiary clays are the most important in the State of Arkansas. As already stated, they, with their accompanying sands, marls, and organic deposits, underlie a large part of the State east and south of the St. Louis, Iron Mountain and Southern Railway south of Arkansas River. North of this and east of the Paleozoic hills the sediments are chiefly Quaternary deposits, except Crowleys Ridge, the lowest part of which is Tertiary. Most of the beds of this series were laid down in the sea when it extended over all of southern and eastern Arkansas and as far north as the mouth of Ohio River. The sediments that were washed into this Tertiary sea sloped gently toward the middle of the gulf, and the hardened beds they formed, now lifted above sea level, still retain that slope. During Tertiary time the land must have risen from beneath the water more than once, for we have at many places beds of lignite that could be formed only as swamp deposits. After the lignites had been formed the land was again depressed and covered by the sea and the accumulation of sediments continued. Everywhere over the area those sediments were laid down in beds that were approximately horizontal but dipped gently seaward. After the final elevation of these beds above the sea, the streams carved out our present topography in the uppermost of the Tertiary beds.

From this brief sketch it will be seen that the sediments laid down during Tertiary time vary from place to place in thickness and in character, just as any marine sediments of the present time vary. Some of the beds are clays and some of them are sands and gravels. The fresh-water or land deposits also vary, just as such deposits vary at the present time.

The fire clays of the Crowleys Ridge region are everywhere associated with beds of Tertiary lignites, which outcrop in the basins of several of the larger streams. Lignites and fire clays occur in the NE. ¼ NE. ¼ sec. 26, T. 4 N., R. 4 E.; NW. ¼ SW. ¼ sec. 8, T.

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11 N., R. 4 E.; NE. ¼ NE. ¼ sec. 20, T. 10 N., R. 4 E.; sec. 30, T. 16 N., R. 5 E.; and in sec. 36, T. 19 N., R. 6 E.

At each of these localities the fire clays underlie the lignite beds, and from this relation it is fair to infer that similar clays occur under all the lignite beds in this area. No attempts have been made to use these clays for making fire bricks or tiles.

In the first-named section, which is in St. Francis County near the Lee County line, on the east side of Crowleys Ridge, the exposure is well up in the hillside, facing a small ravine tributary to St. Francis River. The clay is from 3 to 4 feet thick, but is difficult of access and extensive stripping will be required to mine it, or if a drift be made into the hillside it will require timbering. This clay is light drab in color when wet, but it dries to white or nearly white.

The association of lignite and fire clays serves to explain the light color of the clays. Around all the lignite deposits in the Crowleys Ridge region there are extensive beds of blue or black clays, containing selenite crystals, which pass into these light-colored clays by hardly perceptible gradations. Some masses of lignite detached from great beds near at hand are imbedded in the horizontally stratified blue clays that overlie the lignite beds. The clays in contact with these masses are lighter colored, some of them almost white, having apparently been bleached by the action of the organic matter of the lignite. The lighter color of the underlying fire clays is due to the same processes. Organic matter that finds access to clays and soils acts as a powerful discoloring agent; from black or blue or even red they may be changed to drab or white. This phenomenon is well illustrated along Copperas Creek in Cross County, near La Vesque, at the base of the great section there exposed, and also along the base of the Cherry Valley section, where the organic matter is in the form of leaves and other vegetable detritus. In Greene County, in sec. 35, T. 19 N., R. 5 E., and along the clay bottoms of Bolivar Creek, at the point where the lignite forms the base of the cliff in sec. 8, T. 11 N., R. 4 E., similar phenomena are to be seen.

At the Cherry Valley locality the lignite outcrops on the surface of the ground, and not far away from it is an outcrop of the underlying fire clay. This clay forms the bed of Bolivar Creek for a distance of half a mile or more, passing under it and into the high bluffs that face it. A local dip of this bed carries it under the bed of lignite that outcrops in the bottom of Bolivar Creek a half mile or more to the west. At the locality of best exposure it passes northward under a cultivated field and doubtless extends entirely beneath it. A quarter of a mile farther east it again appears in a thin bed higher up in the hillsides, and finally disappears under a heavy talus derived from the adjacent hills.

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At the point of the section where the lignite is exposed in its greatest thickness 3 or more feet of this clay appear in the hillside facing the stream. It is chocolate brown when wet, its color being due to the presence of minute particles of finely divided lignite, for there is no other coloring matter present.

The third locality is on a small stream known as Otter Creek, 1½ miles northwest of Bay Village. The drab fire clay is about 2 feet thick on the immediate bank of the stream. The clay extends over much of the surrounding region and is of comparatively easy access. It has been put to no use thus far.

The fourth locality is in Greene County, on the banks of Beech Creek, where the fire clays are indurated into a soft light-drab shale with conchoidal fracture. It passes under a cultivated field near the stream to the west and disappears in the high hills that border the creek on the east.

Above the clays in this Beech Creek section lie indurated and quartzitic Tertiary sandstones. If these deposits are ever deemed of sufficient importance to work, they can be ground so that they may be used. The outcrop extends for a long distance up the stream, and there is no doubt that these clays underlie all the country immediately adjoining.

Another locality in Greene County where fire clays occur is southwest of the place last mentioned, in sec. 10, T. 17 N., R. 4 E. An analysis of this clay was made at the St. Louis Sampling and Testing Works and is reported as follows:

Analysis of clay from Greene County.

Moisture	17.64
Combined water and organic matter	6.63
Silica (SiO_2)	70.43
Alumina (Al_2O_3)	19.15
Lime (CaO)	.52
Magnesia (MgO)	Trace.
Iron	1.70
Alkalies	1.84
	100.27

The clay at this place outcrops on the side of a hill, in a ravine near its base, and may be connected directly with that found at the Lovelady place, in sec. 30, T. 18 N., R. 5 E. It could be employed in the manufacture of fire bricks of ordinary grades, as well as for sewer pipes, tile work, and similar uses.

In sec. 30, T. 19 N., R. 6 E., there is a deposit of fire clay in the bank of a small stream. Probably the same bed is reached in a well in the Cache bottoms, 1½ miles farther southwest. These beds appear to be related to those on Beech Creek near Lovelady. They

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are of drab color and are exposed in the stream to a thickness of 5 feet or more.

No pottery clays are known in the Crowleys Ridge region. It is probable, however, that local deposits may be found in some of the low grounds of the slashes of the region.

Throughout the Crowleys Ridge country, wherever erosion has gone deep enough to reach the cross-bedded Tertiary sands, it has exposed numerous thin undulating strata of bright-red, pink, purple, gray, white, or yellow ochers. In certain localities, as in the Prussian Jewish Cemetery at Helena; at Double Head Bluff, in St. Francis County; at Wittsburg, on Wolf Creek, in Poinsett County; at Gainesville, in Greene County, and at Chalk Bluffs, in Clay County, these clays are found in abundance. Commonly, however, they are much intermixed with sands and are very patchy in their occurrence.

The only uses to which they are known to have been put are for painting outbuildings and fences and in dyeing cloth. Since they are so local in occurrence and are commonly found in small quantities they are not believed to possess any economic value.

Analysis of pink clay from Gainesville, Greene County.

[Specimen dried at 110°–115° C. Brackett & Smith, analysts.]

Silica (SiO_2)	71.17
Alumina (Al_2O_3)	18.44
Ferric oxide (Fe_2O_3)	2.77
Lime (CaO)	.25
Magnesia (MgO)	.44
Alkalies, by difference	.90
Loss on ignition	6.03
	100.00
Air-dried sand in air-dried clay	14.52

In the roadway on the west edge of the village of Gainesville several feet of this clay outcrops in pockets. There is no continuous deposit of it in the immediate vicinity of the village, though one occurs in deep washes near the roadway in sec. 32, T. 18 N., R. 5 E. In this locality the pink pipe clay occurs in beds that range in thickness from 4 to 15 inches and are separated by cross-bedded white sands.

At Wittsburg there is another deposit of pipe clay which is characteristically patchy and wanting in continuity. In the west edge of the village, in a gulley crossed by the roadway leading to Wynne, there are beds of pipe clay that are in places as much as 3 feet thick. In color they range from white to deep red, through drab, yellow, and pink. A sample of the red and pink clay of this locality was analyzed with the following results:

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Analysis of pink clay from Wittsburg.

[Specimen dried at 110°–115° C. R. N. Brackett, analyst.]

Silica (SiO_2)	69.55
Alumina (Al_2O_3)	15.20
Iron oxide (Fe_2O_3)	8.10
Lime (CaO)	.58
Magnesia (MgO)	.97
Potash (K_2O)	.52
Soda (Na_2O)	.50
Phosphoric acid (P_2O_5)	.20
Loss on ignition	5.72
	101.34
Water at 110°–115° C	2.24
Air-dried fine white sand	25.48

QUATERNARY CLAYS.

The Quaternary deposits of Arkansas occupy a large area east and south of the Paleozoic group. South of Arkansas River these deposits, except along the larger streams, are comparatively thin, and between them lie many outcrops of the underlying Tertiary and Cretaceous sediments. North of Arkansas River the Quaternary deposits are much thicker. In all the flat country of northeastern Arkansas Quaternary deposits completely cover all the older formations. Tertiary rocks outcrop along the base and sides of Crowleys Ridge.

Crowleys Ridge enters the State in Clay County and runs due south to Helena, in Phillips County. The country traversed by this ridge is low and, from a geologic point of view, somewhat monotonous. Its geology as related to the clays and clay industries can be presented most conveniently by a brief statement of the geologic features of Crowleys Ridge itself.

The Quaternary clays of the Crowleys Ridge region are either (1) loess or ridge clays, or (2) ridge-land clays, found west of Crowleys Ridge.

The first of these soil and clay groups is found mainly on the higher portions of Crowleys Ridge. The second occurs only on the more elevated portions of the low country, but its chemistry and distribution present certain peculiar and interesting facts that call for its separation from the soils of the lowlands proper.

From Helena nearly to Jonesboro the loess is the characteristic soil of the higher portions of Crowleys Ridge. At some places where ravines are eroded along the eastern margin of the ridge, at right angles to its trend, this material forms precipitous walls, the bottoms of which rest on gravels and sands. In other localities loess soils overspread the slopes of the hills to varying depths. These redeposited loess soils are not so homogeneous as the undisturbed

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portions of the loess, for they contain more or less gravel and sand, derived from the neighboring hills.

The limonitic buckshot lands, as has already been stated, are widely distributed, for, owing to the method of their formation, they are liable to be made wherever the conditions indicated exist. Therefore the buckshot are not confined to clays of any particular age. The conditions most favorable for their formation, however, as might be expected, have existed and still exist in the widespread flat Tertiary and post-Tertiary portions of the State, and in the hardpan of the prairie region.

The region between Crowleys Ridge and White River is diversified with prairie and wooded lowlands and traversed by low ridges which have a general north-south trend parallel to the drainage lines. Though they stand only from 5 to 15 feet above the general level, they nevertheless constitute a remarkable topographic feature. On these ridges several towns and villages are located—Surrounded Hill, Brinkley, Wheatley, and Palestine, for example.

The geology of these low divides is not positively made out. The soils which usually cap them are entirely different from those which form the surface of the distinctively prairie region. It is commonly a yellowish-brown loam resembling the loess soils of Crowleys Ridge, but it is not an alluvium. Beneath it are the buckshot clays, as is shown in well sections. Extensive deposits of this loam occur in portions of secs. 10, 11, 14, 15, and 22, T. 3 N., R. 2 W. The ridge extends away toward Clarendon, but disappears in the pine flats a few miles south.

The buckshot clays cover nearly all the country contiguous to and west of Crowleys Ridge. They also form a narrow belt along the eastern edge of the ridge south of Poinsett County; but this eastern belt entirely disappears at places in the southern portion of the ridge. These clays have been noted at but few places in the country east of St. Francis River, where the lands are composed mainly of alluvium, and are in great part subject to periodic overflows. In the region west of the ridge these clays constitute all the second bottoms along L'Anguille, Cache, and White rivers, and at many places along those streams they appear from beneath the alluvium. This statement holds also for the White River region south of the Bald Knob and Memphis branch of the Iron Mountain and Southern Railway. The entire prairie region of St. Francis, Cross, and Poinsett counties is underlain by this soil. Farther west, in Woodruff, Monroe, Prairie, and Lonoke counties, it is commonly observed either in the washes on the prairies or in the "post-oak slashes" of that region, and is penetrated in all well sections. All the post-oak regions of the Crowleys Ridge area are characterized by soil of this sort. In some localities, as at Forrest City, Marianna, Jonesboro, and Paragould, it

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ascends the slopes of the hills a number of feet (at some places as much as 40 feet) above the general level of the surrounding region. It occurs also in occasional small basins at the very top of the ridge, but is there mixed with loess and is not so sandy as it is in the lowlands. In many localities in the Cache and L'Anguille bottoms it rises to the surface and forms the soil over extensive areas.

The buckshot clay is commonly a light-gray sandy clay, nearly impervious to water, containing an abundance of small nodules of limonite. There are usually several thousand of these little nodules to the cubic foot of earth. At many localities the clay is removed from the soil, or it never was present, so that the soil now consists of only the coarser sands and the limonite. These nodules lie in countless thousands on the surface, giving a characteristic lumpy surface to the soil, which, where they so occur, is too poor to support even a scanty vegetation. Along the borders of some streams and ravines the nodules have weathered out to form layers a foot or more in thickness, notably at the mouth of England Creek (in the NE. ¼ SW. ¼ sec. 19, T. 10 N., R. 4 E.) and in the valley of Big Creek about Jonesboro.

In general, then, it may be said this limonitic hardpan, or buckshot, is found over all the low country for 50 miles or more west of Crowleys Ridge. On the east of the ridge it is but a narrow fringe along its base below Poinsett County, but north of this county it spreads over the whole region as a subsoil, in places rising to the surface and varying in depth from 3 to 7 feet. It extends eastward to the alluvial bottoms of the St. Francis. Along Cache River in Greene and Clay counties much of the land is made up of these slashes or buckshot soil.

This buckshot soil is used at Jonesboro, Gainesville, Paragould, and Rector for the manufacture of bricks, but it is ill suited for this purpose. The limonite is reduced to metallic iron in the parts of the kiln next to or near the fire, and this gives the bricks a black, spotted appearance, which contrasts unpleasantly with the color of the body of the brick. In the yards employing this brick earth the processes of molding are crude and none of the higher grades of machinery are in use; all the bricks are hand molded and none are re-pressed.

REMARKS ON THE ANALYSES.

Comparison of the analyses given in the table on pages 236–237 will help to an understanding of the colors of the bricks made in the region. Clay for making bricks of good red color should contain iron; clay for brown bricks should contain manganese. The brick earths from Paragould and Jonesboro and one sample from Harrisburg contain most manganese; the others contain but a trace or none

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of it. The rich colors of the Jonesboro-Paragould bricks therefore seem to be due to these two substances. Clays that are deficient in both these substances, or that contain one of them in lumps—as the soil from the buckshot land at Harrisburg—will make bricks of poor color, which, however, may be modified or improved by the addition of soils containing iron or manganese.

The colors of bricks depend also on the degree of heat to which the kilns are raised and the chemical combination of the iron or manganese. Careful manufacturers of bricks keep close watch on these important factors and produce bricks of uniform color and hardness. In the Crowleys Ridge region the refinements of brick manufacture have not been attempted, although the loess soils found there are preeminently suited to the production of fine brick.

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CHAPTER IV.

REPORT BY COUNTIES.

ARKANSAS COUNTY.

The southern portion of Arkansas County lies in the flat bottom lands of White and Arkansas rivers. The central and northern parts are higher. All the large streams of the county flow south. Between the streams are gently rolling prairies, which vary in width from 2 to 15 miles. The Stuttgart and Arkansas River Railroad follows the main ridge or prairie land from Stuttgart to Gillett. The ridge ends about 5 miles south of Gillett.

The prairie or ridge land in the northern part of the county extends eastward to White River. From near Searcy to Crocketts Bluff, in Arkansas County, a series of bluffs or steep banks extend along the west side of White River. The character of the country along the river is made apparent by such names as Devall Bluff, Mount Adams, and Crocketts Bluff. South of Crocketts Bluff the high bank on the west side of White River gradually falls away into low bottom lands.

The soils of the county fall naturally into two groups—(1) the alluvial sandy soils along the rivers and large streams and (2) the prairie soils. The soils of the prairie lands are reddish to gray clay, which has a maximum thickness of 30 feet. Below the surface clay comes a bed of quicksand, or common fine sand, which furnishes the water supply for the shallow wells of the district.

The following well record at Stuttgart gives the characteristic strata of the prairie lands:

Section of strata at Stuttgart.

	Feet.
Drab-colored clay	1– 1½
Red to brownish clay	8–10
Reddish sand	3–15
Red or blue clay, locally called soapstone	8–15
Gray quicksand	3–30
Gravel, water bearing	3–12
Quicksand	(?)
Clay	(?)

A bed of lignite is found at many places just above the bed of gravel.

The only clay product manufactured in the county is common building brick, made from the surface red clay at Stuttgart.

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ASHLEY COUNTY.

The rocks all through the higher parts of the county belong to the Eocene (Tertiary). The lowlands along Saline River, on the west and east of Overflow Creek, and along Bayou Bartholomew are mostly alluvial lands, where only brick clays may be looked for; or they are "slashes," where occasional pockets or thin beds of common pottery clays may be found.

The beds of the higher portions of the county are nearly horizontal and consist, for the most part, of sands and clays in various combinations and occasional beds of lignite.

The well sunk at the court-house at Hamburg is said to have passed through the following section:

Section in well at Hamburg.

	Feet.
Sandy soil	3–4
Not recorded	23
White pipe clay	10
Red clay	3–6
White quartz sand	20
Pebble bed.	

The pipe clay of this well section suggests that valuable clays may be found at some places in Ashley County, probably on slopes where the streams have cut deep into the soil. They will probably be found also in the deep wells.

G. D. Harris, while working on the geology of Ashley County, was informed that in the wells "a blue or light-gray clay occurs to a depth of 40 feet. This clay contains some leaf impressions." The character of plant-bearing clays found in other counties in Arkansas suggests that the clays may be available for making pottery and for other purposes.

The only clay-working industry in Ashley County is a common brick plant run by Nolly Brothers at Hamburg.

BRADLEY COUNTY.

The northern and western part of Bradley County is a rolling country which slopes gradually toward the bottom lands of Ouachita River. On the east the lands drop away rather abruptly toward Saline River. Along the larger streams—the Ouachita, the Moro, and the Saline—the soils are mostly alluvial, and the original Tertiary sedimentary beds are exposed at only a few places. G. D. Harris states that "the undisturbed Tertiary deposits of Bradley County consist of light-colored lignitic clays, usually intermixed with more or less light-colored siliceous sand. Bluish or black clay is occasionally met with in digging or boring wells, and there is some pure lignite."[a]

[a] Tertiary geology of southern Arkansas: Ann. Rept. Geol. Survey Arkansas for 1892 vol. 2, p. 119.

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He found gray clays exposed on the road running north from Johnsville toward Warren and 4 or 5 miles from the former town. He gives the following record of the well of Lee Hammaker, in sec. 8, T. 12 S., R. 6 W.:

Record of well of Lee Hammaker.

	Feet.
Light, even-bedded clay	28
Clay ironstone	2
Reddish-white and yellow clay	5
Blue fossiliferous clay	6
Clay ironstone	1
Black sand with water	5

At Alga Bluff, on Saline River, in sec. 21, T. 13 S., R. 9 W., a section about 75 feet thick is exposed. The lower half of this section contains two thin beds of lignite and two beds of clay—one 3 feet thick, between the beds of lignite, the other 16 feet thick, overlying the upper bed of lignite. These clays have not been examined chemically, but they are worthy of examination and practical tests.

At Crawfords Bluff, on Saline River, beds of lignitic clay are exposed again. In the region between Johnsville and Long View, wherever the drainage has cut deep channels, these lignitic potter's clays are to be looked for beneath the heavy gravels.

About one-half mile west of the point where the railway from Monticello to Warren crosses Saline River the railway cuts a terrace-like ridge. The upper 4 feet exposed in this cut is a bright-red soil, and the underlying bed is purple clay.

About Warren the surface loam is in many places adapted to brick-making, but so far as could be learned no clays of importance beyond the brick earths have been found in the immediate neighborhood. The Tertiary (Eocene) fossiliferous beds are exposed in the railway cut in the town. Over all of Bradley County the Tertiary (Eocene) beds are either exposed at the surface or are concealed by their own weathered remains or by a thin sheet of Pleistocene gravel and sand. Most of the weathered Tertiary clays of this county form excellent brick clays.

In sec. 20, T. 14 S., R. 9 W., a well dug beside the road leading from Warren to Johnsville has the following section:

Section in well in sec. 20, T. 14 S., R. 9 W.

	Feet.
Sandy loam	2
Red sandstone with pebbles	8
White pipe clay	4
Sand.	

It may reasonably be expected that valuable clays will be found in connection with the lignites known to exist at various places in

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Bradley County. One of these exposures of lignite was visited at Goulets Island, on Saline River, in sec. 24, T. 17 S., R. 10 W. The following section is exposed on the left bank of the stream at that place:

Section at Goulets Island, Saline River.

	Feet.
Sand and clay	6
Clean sand	10
Pebbles and sand	10
Lignite	2
Blue-gray sand and clay	2

The only clay in this section underlies the lignite, and is too far below the surface and contains too much sand to be of any practical value. The lignite is too thin to be worked and has no value

Several years ago the statement was published that "Thirty-six varieties of commercial clays and shales * * * have been found * * * within a radius of 3 miles from the town [of Warren], of which twenty consist of material used in the manufacture of vitrified pipe and paving brick, and the remainder * * * material used in the manufacture of terra cotta, drain tile, earthenware, and pressed brick."[a] Such a statement must be accepted with allowances. As pointed out elsewhere in this report, whether a clay is available for a given purpose can generally be determined only by practical tests. It should not be forgotten also that a clay, in order to be commercially useful, must be abundant, accessible, and cheap. In spite of the fact that the clays of Bradley County have not been tested as they deserve to be, the geology of the county leads to the reasonable belief that it contains large bodies of valuable clays. Only one establishment in Bradley County is engaged in the manufacture of clay products. This is a plant for making common soft-mud brick, located at Warren, and operated by Moore & Gannway.

CALHOUN COUNTY.

GENERAL GEOLOGY.

The geology of Calhoun County can best be understood by a study of the bluffs exposed along the right bank of Ouachita River in Union and Ouachita counties. These bluffs are made up of a series of clays, sands, and lignites which rise to a height of 200 or more feet above the ordinary stage of the water in the river. These soft beds now end abruptly at the river or at the margin of its immediate valley, but originally they extended across what is now the flood plain of the Ouachita and covered Calhoun County, as they still do, though in a modified way.

[a] De Malher, M. L., Arkansas Gazette, January 20, 1884, p. 5.

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The section observed on the right bank of the Ouachita at Wilmington Landing gives a better idea of the geology of Calhoun County than any single exposure known in the county itself. That section is therefore repeated at this place.

Section at Wilmington Landing.

	Feet.
Sand on the hilltop	2
Sandy clay	5
Light-gray clay	2
Pinkish clay	3
Fat buff clay with sandy patches and lignite	16
Tough, sandy light-colored clay	7
White sand	3
Brown coal or lignite	3
Fat dove-colored clay	3
Sand with clay laminæ	5
Pink sandy clays and sands	10
Concealed	10
Level of Ouachita River	90

In dealing with the geology of Calhoun County we should remember that the beds exposed in the section at Wilmington Landing formerly covered the region to the east and north, and that water has gradually cut away the beds and lowered the whole land surface to its present level.

Beyond the river at Wilmington and farther north, toward Summerville, for several miles, the country is very nearly flat and but little elevated above the flood plains of the river. There is, however, an almost imperceptible rise as one approaches Hampton, and a short distance north of Hampton the country is at or about the same elevation as the elevated country at Wilmington Landing.

Over the lower country in the southern part of the county, and indeed almost everywhere east of the Ouachita, the lands are made up of river silts and alluvial and buckshot clays, so common in the slashes and boggy "crawfish lands." This surface covering is of later date than the underlying stratified beds, which are everywhere obscured. The Recent materials cover the older sediments throughout the county by spreading out over the flood plains of all streams.

On the higher lands of Calhoun County there is a widespread overwash of waterworn pebbles. Most of these pebbles are of novaculite, but many quartz pebbles are mingled with them. The novaculite that makes up the great bulk of the gravels is so restricted in its distribution that there can be no question about the origin of these pebbles. The novaculite rocks extend from a point near Little Rock on the east to Hot Springs and Dallas, in Polk County. Almost everywhere they form mountains, generally very steep and rugged. It is from these mountains of novaculite that the novaculite pebbles have been spread out like a great blanket over all the counties

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of the State lying south of the Ouachitas or novaculite ridges of Pulaski, Saline, Hot Springs, Montgomery, Pike, and Polk counties. The quartz of the pebble beds is doubtless derived from the same region, for the novaculite shales are noted for the great number of thin quartz veins they contain. The fact that the pebbles generally underlie the silts and alluvial beds of the flood plains of the streams shows, too, that they are older than these silts. They seem to have been brought to their present position at the time when the Tertiary land was emerging from the bed of the sea, having been spread out by the undertow of the retiring waters.

These gravels are most abundant on the tops of the highest hills of the region, where they make excellent roads, or beneath the soils along streams. This is because they were originally spread over an approximately flat region; subsequent erosion has removed some of this material, thus making valleys in which the gravels are concentrated beneath the silts and soils that have later accumulated above them.

CLAY DEPOSITS.

Beneath the gravels and immediate surface soils lie the soft Tertiary beds referred to as cropping out in the bluffs of the Ouachita. These deposits contain many beds of pottery clay. Only a few of the outcrops of these beds can be noted here, but anyone who will bear in mind the general geologic structure of the region, as stated above and as shown in the section on page 17, can readily trace the beds and will know where to look for these clays when they have been found at a single locality.

About 3½ miles north of Hampton, at a point where the Hampton-Chambersville road crosses Rocky Branch, on the slope of a hill about 150 feet south of the stream, is a bed of greenish-gray potter's clay. It is not well exposed and neither its upper nor its lower limit could be seen when the place was examined, but it appears to have a thickness of about 4 feet. It can not be stated positively that the clay exposed is in place, but if it is the bed will be found to continue both up and down Rocky Branch at the same elevation, and it is quite probable that it may be found also on the north side of this stream at about the same elevation.

About 3 miles south of Chambersville, just south of Whitewater Creek, at a place where the Hampton-Chambersville road ascends about 40 feet from the bottoms to the higher land, probably in the SW. ¼ sec. 3, T. 12 S., R. 13 W., potter's clay is exposed in the face of the hill in the road. The thickness of these beds can not be determined without digging, but they seem to be from 10 to 20 feet thick at the place mentioned, and are well above all possible overflow of the neighboring streams. The outcrop extends around the face of the hill to the northeast and southwest from the road, while the

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beds penetrate the hill to the south. In all probability the outcrop will also be found following the face of the hills that skirt the valley of Whitewater Creek along its right bank.

In the Chambersville-Hampton road, a little more than a mile south of the outcrop last mentioned, similar potter's clay is exposed in a gully on the north side of the road.

About 2 miles south of the point where the same road crosses Whitewater Creek potter's clays are exposed again by the roadside in the brow of a low hill facing northwest. This place is probably in the SW. ¼ sec. 15, T. 12 S., R. 13 W., about a quarter of a mile southeast of Dawson's schoolhouse. The following is the section exposed:

Section in SW. ¼ sec. 15, T. 12 S., R. 13 W.

Soil with pebbles and silicified wood.	Feet.
Greenish lead-colored clay	5
Brown coal	2
Clayey sands (base concealed)	4

Some of the cobbles in the soil overlying this section are 6 inches in diameter. With the exception of the fossil wood and a little quartz they are all of novaculite.

The outcrops of clay and brown coal extend both to the north and south of the road.

A little more than a mile south of Chambersville, probably in the SW. ¼ sec. 27, T. 11 S., R. 13 W., on Henry Clay's place, a bed of potter's clay 4 or 5 feet thick is exposed beside the road. It contains a few leaf impressions, and in general appearance closely resembles the clays used at Perla. This clay bed will be found to continue to the east of the Chambersville-Hampton road into the woods, while to the west it skirts the low hill north and west of Henry Clay's farmhouse.

Mr. Siebenthal reports a bed of gray plastic clay, from 6 to 10 feet thick, on the railway at a place where it crosses from Cleveland County into Calhoun County, in sec. 4, T. 11 S., R. 13 W., and the same bed again about 500 paces west of the first-mentioned exposure. Good pottery clay is reported on the Jordan place, in sec. 6 of this same township, and also on the Lightfoot place, 1 mile south of Little Bay.

So far as the geology of Calhoun County has been studied it leads to the conclusion that the pottery clays will be found in a long series of outcrops skirting the Champanolle on both sides and along the west side of Moro Creek, following up the larger streams like Whitewater. They will be found also in the hillsides along the upper part of Locust Bayou and along the east side of Two Bayou toward its head. These clay beds vary in thickness and in character, but for all practical purposes they may be regarded as inexhaustible.

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Clays available for ordinary pottery occur here and there in the wet slashes along the larger streams and along Ouachita River, but these deposits are limited in quantity and, as compared with the stratified Tertiary clays, are of inferior quality. It does not appear that the pottery clays of Calhoun County have ever been utilized, even for local purposes, and transportation facilities will need to be improved before the excellent clays of this county can be turned to much account.

CLAY COUNTY.

The only clays of economic importance found in Clay County are common brick clays. The most abundant brick clay is the loess, which occurs on the top and sides of Crowleys Ridge throughout the county. Along a narrow belt of country at the foot of Crowleys Ridge, on both sides, the loess has been reworked by the streams and forms a second bottom. The reworked product is very similar in appearance and composition to some phases of the loess. It usually has a more yellowish color, due to the presence of iron oxide obtained from the highly ferruginous sand underlying the loess on the ridge. Where the yellow second-bottom clay is constantly covered with water the iron oxide is largely leached out and the clay becomes a white glady soil.

The second-bottom land is much narrower on the west of the ridge than on the east. Patches of country between Cache and Black rivers are covered with white to gray buckshot clay. It is doubtless of the same age as the white glady land on the east side of the ridge. At various places in the county between the west edge of Crowleys Ridge and Current River the surface is covered with alluvial sand, which overlies the hardpan or buckshot clay where the latter has not been removed by the present streams.

The reworked loess at Pratt is being made into common building bricks by the Pratt Brick Company. This is the only plant in the county engaged in the manufacture of clay products.

CLEVELAND COUNTY.

GENERAL GEOLOGY.

The geology of the extreme northwestern part of Cleveland County is similar to that of Saline and Hot Spring counties; that of the central part is like that of Union and Calhoun counties, where there are so many good clays; while that of the southeastern portion is like that of Drew and Ashley counties. It is probable that there are many clay deposits in Cleveland County available for pottery, fire bricks, sewer pipe, etc.

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The work in Cleveland County was done by Prof. G. D. Harris, who gives the following résumé of the geology of the lowest beds in the northwestern section:[a]

A small portion of the northwestern quarter of this county is doubtless underlain by lignitic deposits. Records of well-borings at Pinchback's mills, according to Mr. J. C. Simmes, of New Edinburg, show no traces of molluscan remains. The materials commonly passed through are sands and dark lignitic clay. In the vicinity of Cross Roads Church, about 4½ miles northwest of Kingsland, fossils belonging to the Jackson horizon were found in the form of casts and impressions in concretionary ferruginous sandstone. Wells near Kingsland and farther west are said to pass through 25 or 30 feet of sandy clay of a light-yellowish color, and then to encounter bluish clay or lignite. The bluish clay at some places continues for 30 feet or more, when it gives way to soft and sandy material that furnishes water in abundance.

The higher beds that cover all the central part of the county belong to the middle or Claiborne division of the Eocene (Tertiary), and are similar in the main to the beds of Calhoun and Union counties.

Below is given the record of a well on the land of J. B. Williams in the SW. ¼ SW. ¼ sec. 1, T. 9 S., R. 11 W.

Record of well on land of J. B. Williams.

	Feet.
Soil and sands	20
Joint clay	20
Clay with gypsum	10
Shells	10
Leaves	5
Dark-blue earth	12
Coarse white sand	4

On Mount Elba, just south of Bridges Bluff on Saline River, 3½ miles south of Toledo, the following section is exposed:

Section at Mount Elba.

	Feet.
Pebbly dark soil	2
Yellowish clayey sand	7
White chert pebbles	7
Light lignitic clay	3
Concealed to the water	15

Several other sections reported by Professor Harris in Cleveland County contain clays, but it is not clear whether they are valuable. Bed No. 4 in the following section reported by him appears to be one of promise. The locality is 5 miles southwest of New Edinburg, on the Moro Bay-Pine Bluff road.

Section near New Edinburg.

	Ft.	In.
Soil, sand, and a few pebbles	2	
Light, evenly laminated blue-gray clay	4	
Light-gray micaceous clay		6
Leaf-bearing bluish-gray clay	8	

[a] Ann. Rept. Geol. Survey Arkansas for 1892, vol. 2, p. 57.

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CLAY INDUSTRY.

There is an abundance of good brick clays over a large part of the county. The Leali Pressed and Fire Brick Company's brick plant at Kingsland, with a capacity of 20,000 bricks a day, has been in operation since about 1901. The plant manufactures dry-pressed, stiff-mud, and fire brick. Shale and common clay are used. The bricks are dried in a Standard steam drier, and burned in both up-draft and down-draft kilns, which hold from 75,000 to 400,000 bricks. The Raymond stiff-mud machines and the Berg dry-press machines are used. The former has a capacity of 40,000 and the latter of 20,000 bricks a day.

The company is preparing to move its plant to Little Rock, and will operate there under the name of The Southern Brick Company.

COLUMBIA COUNTY.

CLAY DEPOSITS.

All of Columbia County lies within the Tertiary-Quaternary region. The general geology of the county is favorable to the discovery of pottery, tile, sewer pipe, and refractory clays, and wherever such beds may be found the horizontality and uniformity of the geologic structure will make prospecting for them very simple.

The details of the geology of Columbia County have not been sufficiently studied to determine the precise geologic position or the geographic distribution of the more valuable clays, but clays of excellent quality will doubtless be found in abundance in the county. It seems most probable that they will be found not in the higher parts of the great watershed that runs through the middle of the county, but well down its sides and along the sides of the valleys of the larger streams.

The usual "deer-lick" clays are found in the wet slashes, but it is not thought that clays of this class are of sufficiently good quality or sufficiently abundant to warrant exploitation, except, perhaps, in a very limited way, to meet small local demands. The stratified clays are abundant and good, and when a good bed is found there is never much difficulty in determining its relations to the accompanying beds or in tracing it over the adjoining country.

On the road leading from Magnolia to Mount Holly, in the NE. ¼ sec. 3, T. 17 S., R. 20 W., there are some greenish-gray pottery clays, at least 3 feet of which is exposed. The upper part of this bed is discolored by iron, but the discoloration seems to be only superficial. Sandy fire clays are exposed in a gully on the side of the same road 9 miles east of Magnolia.

At a few places between this locality and Mount Holly there are small outcrops of pinkish sandy clays containing leaf impressions,

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but as a rule these beds are too sandy to make good pottery clays. The probabilities are, however, that the same beds at localities other than those examined may yield excellent clays, since they are of the same general character and appearance and contain the same fossil leaves as the pink fossiliferous clays used successfully at Perla switch, in Hot Spring County.

A quarter of a mile west of Mount Holly some promising-looking dove-colored clays are exposed at the side of the road. This clay, however, contains a few pebbles, and it may not prove to be of value. Beneath this gray clay are pinkish beds with leaf impressions.

The following is the record of a well dug by Mr. G. O. Bailey on his land near Magnolia, in the N. ½ sec. 34, T. 16 S., R. 20 W.:

Section of Bailey's well near Magnolia.

	Feet.
Surface soil	6
Cream-colored clay	15
Sand and pink clay mixed	3
Brown potter's clay	5

The second bed in this section contains a good many impressions of plants. The clay has not been analyzed, but its texture and color suggest its availability for the manufacture of good pottery. It contains 39.44 per cent of cream-colored sand. This sand is very fine, only 1 per cent of it being caught on a wire gauze having 100 meshes to the inch and 3 per cent on one having 150 meshes to the inch, the remainder passing through.

The third member of this section is of a light-pink color. It is very fine and clear of grit, but this pure part of the clay is so mixed with small pockets of rather coarse sand that in its present condition it is not available for fine pottery. The occurrence of this bed, however, is interesting, and suggests that a clean bed of excellent clay may yet be found. There is 29.08 per cent of clean white sand in clay No. 3, which includes that of the sand pockets as well. A large part of the sand, 36 per cent, is caught on a sieve having 100 meshes to the inch. In order to determine whether the body of it might not be kaolin the sand was washed from a sample of No. 3 and the water expelled by ignition. The loss was 9 per cent. The percentage of water in true kaolin is 13 per cent, while ordinary clays have 5 and 6 per cent. This can not, therefore, be regarded as a sandy kaolin, although it contains a higher percentage of water than ordinary pottery clays.

The brown clay in which the well ends is identical in color and texture and general appearance with the brown clays successfully used at Perla switch in the manufacture of pottery and fire bricks. It contains 28.92 per cent of fine light-brown sand, the lower brown clay at Perla switch containing 21.9 per cent. All the sand in this brown

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clay is very fine, only a little more than 1 per cent of it being caught in a sieve having 150 meshes to the inch, the remainder passing through. This lower bed, like that at Perla, contains many impressions of leaves and stems of plants; indeed, the whole section seems to be very similar to the clay pits at that place.

It is reported that clays similar to those found in Bailey's well have been passed through in digging several wells in the neighborhood, and that in some of them the lower brown clay has been penetrated to a depth of 10 or 12 feet without having been passed through.

CLAY INDUSTRY.

The McIntyre Company has a small brick plant at Magnolia. The plant was established in 1884. Surface clay is used, from which is made a red common building brick. The bricks are molded by hand, dried in the open air and sunshine, and burned in an up-draft kiln. About three days are necessary to dry the bricks sufficiently to place them in the kiln; nine days are required for burning. Wood is used as fuel. The output is 5,000 a day. The molds are 8¼ by 4¼ by 2½ inches.

CONWAY COUNTY.

GENERAL GEOLOGY.

The general geology of Conway County is the same as that of Faulkner County, and the clays of the two counties are therefore of the same character and have the same geologic distribution.

The surface rocks in Conway County, except the later deposits along Arkansas River, are entirely in the "Lower Coal Measures." The hard rocks are alternate sandstones and shales that lie nearly flat in the northern part of the county and are thrown into gentle folds in the southern part. The ridges here, as in other portions of the State, are capped by sandstone or are made up entirely of sandstone, while the valleys are generally underlain by shales.

Starting about 2½ miles west and a little north of Morrillton, the Morrillton anticlinal fold of the rocks runs due east to Cadron Creek, crossing that stream in sec. 8, T. 6 N., R. 14 W. The group of parallel ridges and valleys involved in this fold have a width of 3 miles in Conway County. The relations of these ridges to one another are not apparent to anyone passing across the county on the railway, because the railway does not cut across them, but follows the valleys, and is therefore parallel to the lines of structure.

CLAY DEPOSITS.

Varieties.—The principal clays of Conway County are of the following four varieties:

1. The clay shales and the clays derived directly from them by disintegration.

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2. The limonitic buckshot clays.
3. The leached clays of the slashes.
4. The alluvial chocolate clays of the second bottoms along Arkansas River.

Clay shales.—The clay shales are interbedded with the sandstones and are, in the main, similar in character and distribution to those of Faulkner, White, and Pulaski counties. Where they have the proper composition they are available for the manufacture of paving bricks, sewer pipe, and fire-clay products. No chemical analyses have been made of specimens of shales of White County, but the analyses of the Round Mountain shales of White County and of the Little Rock shales of Pulaski County may be accepted as indicating in a general way the character of the clay shales to be found in Conway County.

Buckshot clays.—The buckshot clays cover a large part of the higher valleys of the county. These are used for making common bricks, but owing to the presence in them of the buckshot or small nodules of iron the bricks are often covered with dark-brown spots. These spots are likely to be produced in any well-burned bricks made of the buckshot clays.

Leached clays.—The leached clays are probably only modifications of the buckshot clays. Both the leached clays and the buckshot clays are derived indirectly from clay shales, and chemically altered by weathering and leaching. Where waters charged with organic acids stand for a long time in shallow pools in the slash lands, the underlying clays are often leached of their iron and made available for the manufacture of coarse pottery. Such clays are found in Conway County in the wet places on the second bottoms of the Arkansas River, Point Remove Creek, and Cadron Creek.

The alluvial chocolate clays of Conway County are in every respect similar in character and topographic position to those of Faulkner County.

Old Lewisburg terrace clay.—At Old Lewisburg, 1 mile south of Morrillton, a red clay caps all the elevations. This clay has a maximum thickness of about 20 feet and shows four distinctly colored beds. As seen at a point 250 yards southeast of the ferry, the exposures in a deep gully are as follows, beginning at the top:

Section at Old Lewisburg.

	Feet.
1. Flesh-colored clay containing much sand	7
2. Dark-red plastic clay containing a few small siliceous concretions	4–5
3. Pinkish clay, with numerous small siliceous concretions	3–4
4. Yellowish and mottled sandy clay overlying the black shale that outcrops along the river south of the ferry	4–5

The dividing line between these beds of clay is fairly distinct, though they grade slightly into one another. Bed No. 2 contains

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less sand, apparently, than any of the others. Bed No. 4 is evidently a decomposition product of the black shale that underlies the region about Old Lewisburg and that crops out along the river bank above and below the ferry. This shale contains much sand, and at some places, as just above the ferry, it contains beds of shaly sandstone. It has a dip of 25° S. Beds 1, 2, and 3 are foreign to this locality and are not derived from this shale bed.

The whole site of the town of Old Lewisburg is underlain by the clay mentioned in the section, except where these beds have been cut through by gullies. Bricks have been made from the clay at the south edge of the town of Old Lewisburg. This clay has about the elevation of No. 1, but the clay exposed in the old pit did not show so much sand as bed No. 1 in the gully where the section was taken. The clay of the pit is red. These bricks are reported by Mr. Morloch, who helped to tear down some of the buildings made from them, to be soft and crumbling. No bricks have been made here since Old Lewisburg was in its prime, many years ago.

Clays south of Morrillton.—The ridges south of Morrillton are each formed by a heavy bed of sandstone, dipping south at an angle of 25°. Between these two sandstone ridges is a black, gritty shale, forming a red brick clay. The shale bed is about 275 feet thick.

This clay resembles that of the valley in which Morrillton stands. The clay in this valley is found mostly on the north slope of the south ridge and on the south slope of the north ridge. Where the same clay occurs in the bottom of the valley it contains more sand than it does on the slopes of the ridges.

Brick clays at Morrillton.—About 150 paces west of the public school building in Morrillton, on the north slope of the ridge, is a bed of reddish plastic clay, from which bricks have been made. This clay is sticky, but contains small iron "buckshot" nodules and is sandy, though the amount of sand is not excessive. This same clay bed extends all along the northern slope of this ridge, which is the first one south of the town. It is uniform in color and plasticity and in the amount of buckshot it contains. It is the product of the decomposition of the black, sandy, southward-dipping shale that underlies the whole valley in which Morrillton is built. This surface clay at no place appears to have a thickness of more than 2 or 3 feet. The clay formerly used at W. M. Morloch's brickyard, a little more than half a mile east of the railway station at Morrillton, is red, contains sand and iron, and is only 1 to 2 feet thick, the partially decomposed underlying shale coming close to the surface of the ground. The shale fragments seen on the surface hereabout are weathered to a light-greenish color. The shale that forms this clay belongs to the same bed as that forming the clay

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at the base of the ridge immediately south of the town, but geologically it is about 200 feet lower. The character, color, and plasticity of the clay are the same as those of the clay west of the public schoolhouse. This plant has now gone out of business.

One mile northeast of Morrillton, at a place where the road runs northward past Thomas D. Hawkins's house, a 2-foot bed of red clay, with little sand, is cut through by the road. Where the road crosses the point of the ridge that rises toward the east from the northeast edge of the town there is a similar red clay.

Red clay like that at the localities described above is to be found on nearly all of the slight elevations in the valley and near Morrillton. The bed does not exceed a very few feet in thickness at any place. It is derived from the bed of black gritty shale that underlies this valley and is all of about the same color, has the same amount of sand, and contains much iron in the form of buckshot nodules. It makes a very good quality of brick so far as hardness and durability are concerned, though its color is somewhat injured for special uses by the black iron blotches.

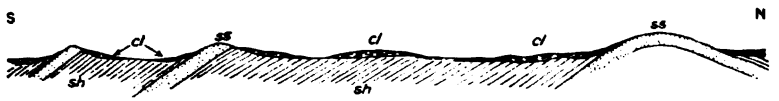

FIG. 6.—Section east of Morrillton. *cl*, Clay; *sh*, shale; *ss*, sandstone.

This clay is good for common bricks or common tiles, but would not be available for sewer tiles, nor can it be used for any other than common bricks.

The shale that makes up the valley is apparently about the same throughout in thickness, color, hardness, and percentage of sand, and yields a pretty uniform residuary clay. The bed of shale is from 550 to 600 feet thick, and under the town of Morrillton and east of it dips south, but turns over the nose of the anticline at the northeast corner of the town and dips north. A north-south section 1 mile east of Morrillton, from the sandstone in the south side of the anticlinal nose to the second ridge south of Morrillton, is shown in fig. 6.

This section represents the thickness of the rocks about 1 mile east of Morrillton, and shows how the clay occurs on the shale in Morrillton. Where the section is taken the clay is mostly eroded away at the north side. At present no clay industries are reported from Conway County.

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CRAIGHEAD COUNTY.

GENERAL GEOLOGY.

The eastern half of Craighead County is occupied by St. Francis River, the Hatchie Coon sunk lands, and a broad belt of low, undrained swamp lands, which extend westward to the narrow fringe of post-oak lands adjacent to Crowleys Ridge.

The country east of Lake City is made up of sunken lands that are subject to frequent overflow, except along some of the slightly elevated areas which are covered with "sandblows." The sandblows consist of fine white sand which has accumulated in small, more or less separate areas and is surrounded by darker colored loam or sand. The country from Lake City to Nettleton is a flat buckshot soil, with a growth of scrubby willow oak, post oak, black oak, and an occasional hickory, white oak, and persimmon. The long-trunked sweet gum and cottonwood are entirely absent.

In the southern part of Craighead County Crowleys Ridge is but one-half mile across, narrower than at any other point between the Missouri line and Helena except where it is cut in two by L'Anguille River in Lee County. North of Jonesboro it widens out, and near the northern border of the county it is broader than at any other point in the State.

The white buckshot land extends westward from the foot of Crowleys Ridge to within about one-half mile of Cache River. Cache River bottom is from 6 to 10 feet lower than the buckshot land to the east, and along the railroad in the northwest corner of the county it is 1 mile wide.

The top of the ridge throughout the county is generally covered with buff-gray to yellowish loess. This is underlain by coarse gravel, which in places has become cemented into a compact conglomerate.

In the northern part of Craighead County the eastern slope of the ridge is more gentle than on the western side. The western slope is very precipitous and affords a better opportunity for the study of the stratigraphy of the ridge.

The following section, obtained 4 miles west of south of Lorado, in Craighead County, affords the best exposure of the Tertiary in the county:

Section 4 miles west of south of Lorado, on the old William Lane place.

	Feet.
Yellowish to Indian red clay on tob of ridge	40
Coarse gravel (Lafayette)	2– 8
Very hard, coarse-grained white sandstone, which in places has become a quartzite	15
Variegated cross-bedded sands interbedded with stratified clays	15

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A continuation of the Tertiary strata in Crowleys Ridge is given below, in a general record of the deep wells at Jonesboro:

Record of deep wells at the city water plant, Jonesboro.

	Ft.	in.
Red clay (loess)	20	
Gravel, mixed with red clay	4	
Joint clay	10	
Coarse yellow sand		10
Pipe clay	25	
Gumbo	10	
Sand, very fine on top, grading downward into coarse sand and gravel, water bearing	60	
Very tough gumbo	50	
Blue mud with iron concretions, extending downward to 1,200 feet.		

CLAY INDUSTRY.

Jonesboro and vicinity.—The brick industry of Craighead County is confined to the vicinity of Jonesboro, on Crowleys Ridge, where five plants have been established for the manufacture of wet-mud and dry-pressed bricks.

The following is an analysis made from one of the brick clays at Jonesboro.

Analysis of brick earth from the surface at Jonesboro.

[Dried at 110°–115° C. Brackett & Smith, analysts.]

Silica (SiO_2)	79.49
Alumina (Al_2O_3)	8.71
Iron (Fe_2O_3)	3.43
Lime (CaO), Magnesia (MgO), Alkalies (by difference)	2.10
Manganese (MnO)	2.44
Loss on ignition	3.83
	100.00
Air-dried sand in air-dried clay	33.40

Jonesboro Brick Company.—One of the largest plants in the State is that of the Jonesboro Brick Company, where soft-mud and dry-pressed bricks are made. The machines for molding the two kinds of bricks are placed under the same shed and run by a central power plant.

The clay used for the dry press is loaded into carts at the pits by hand and drawn to the dry shed, where it is permitted to remain for months before it is made into bricks. When sufficiently tempered it is molded into bricks and set in the kiln. The capacity of the machine is 20,000 bricks a day. The bricks are burned in stationary up-draft kilns, and it requires twelve to fourteen days to burn them.

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When thoroughly burned the bricks are of a cherry-red color and are considered substantial.

The wet-mud machine has a capacity of 30,000 a day, but it requires just twice the number of men to operate it.

The clay used for making the wet-mud bricks is the same as that used in the dry-press machine, except it is not stored in sheds and tempered before it is used. It is hauled from the pit in carts and dumped into small cars, which are drawn up an incline by means of a wire rope attached to a large drum. The cars are unloaded into a bin and fed into the machine by means of a belt with cups upon it. The bricks are removed from the machine and dried on pallets in covered racks. It requires from four to six days for drying, and seven to nine days for burning. Stationary up-draft kilns are used. Wood is used exclusively for burning.

Barton Lumber and Brick Company.—On the lot adjoining the Jonesboro Brick Company's plant, near the depot of the Jonesboro and Lake City Railroad, is the plant of the Barton Lumber and Brick Company, where both wet-mud and dry-pressed bricks are made. The bricks are molded by steam and the wet mud is dried by air in covered racks. They are burned in up-draft clamp kilns, and require about eight days for burning. A kiln that is built 34 bricks high is burned until it settles about 8 inches.

Saxe Brick and Tile Company.—At the time it was visited in June, 1905, the plant of the Saxe Brick and Tile Company was under construction. When completed the plant will have a capacity of 10,000 4-inch tile a day, or its equivalent. Tile will be the principal product if it can be made from the clay. Both soft- and stiff-mud machinery have been installed. The American Clay Worker end-cut automatic machine has been erected for making stiff-mud bricks and tile. Both open-air and steam-heating sheds will be used for drying the product. Down-draft clamp kilns are to be used, wood and coal serving as fuel.

Patrick Brothers Brick Company.—The plant of the Patrick Brothers Brick Company was established in 1905 for the manufacture of soft-mud building bricks. The bricks are made from the common, surface reworked loess clay. They are dried in the open air by means of the pallet and rack system. It requires from six to nine days for drying and from six to seven days for burning. Wood is used for burning. The capacity of the machine is 12,000 to 15,000 bricks a day. The size of the green bricks is 9 by $4\frac{3}{8}$ by $2\frac{1}{2}$ inches. The total shrinkage in drying and burning is $\frac{3}{4}$ by $\frac{1}{2}$ by $\frac{1}{4}$ inch.

Logan & Collans plant.—No particulars of the Logan & Collans brick plant were obtained.

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CRAWFORD COUNTY.

GENERAL GEOLOGY.

The general geology of Crawford County is similar in the main to that of Franklin County on the east and to that of Sebastian County on the south. The southern part of the county—a little more than half of it—is covered by the upper division of coal-bearing rocks of the Carboniferous system. The northern part is made up of rocks that underlie the coal-bearing beds. Most of the rocks of the northern part of the county dip gently toward the south. The coal-bearing rocks are chiefly sandstones and shales, and the valuable clays of the county are to be looked for in these clay shales or in the clays formed by their disintegration. Other kinds of clays of later age that are spread over the lowlands will be spoken of under the head of brick clays.

In sec. 24, T. 9 N., R. 32 W., the following geologic section is exposed along Arkansas River in the hills north of the town of Van Buren.

Section in hills north of Van Buren.

	Feet.
Gray sandstone on hilltop	20
Slaty shales	120
Hard gray sandstone	20
Dark slaty shales	170
Sandstone	4
Dark shale at base.	

Especial attention is directed to this section as showing the enormous thickness of the shales of Crawford County in the vicinity of Van Buren, on the very banks of Arkansas River. The importance of the section and the thickness of the shales will be seen when it is realized that many of these shales are available for the manufacture of paving bricks, sewer pipes, and certain fire-clay products It should be remembered also that these same beds spread over a considerable part of Crawford County.

One other section may be given as a type of Crawford County rocks and their sequence. This section is on the east part of the hill in the SW. ¼ sec. 12, T. 10 N., R. 29 W.

Section in SW. ¼ sec. 12, T. 10 N., R. 29 W.

	Feet.
Brown sandy shale	15
Flaggy sandstone	10
Sandy shales	10
Thin-bedded sandstone	10
Sandy shale	5
Massive sandstone	10
Concealed	40

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	Feet.
Dark-gray shale	20
Compact sandstone	20
Shale	20
Concealed to the creek bed	80

Some of the shales in the above section are sandy, but sandy shales are liable to become argillaceous as the beds are traced from one locality to another.

CLAY DEPOSITS.

Character of material.—Especial emphasis should be laid upon the fact that the value of the clay shales of Crawford County is untested. Not long ago it was supposed that only plastic clays were available for the manufacture of paving bricks. The experience of the brickmakers of Fort Smith, Ark., as well as that of manufacturers at Cheltenham, Mo., and other places, shows that many shales are available for brickmaking when properly treated. The localities mentioned here must not therefore be regarded as the only ones in the county, or even the most important ones. They are merely a few beds that were noted in the course of work done along other lines of investigation. The notes on clays in section 10 are by C. E. Siebenthal; the remaining notes on the clays of Crawford County are by William Kennedy.

Plastic clays.—A plastic cream-colored clay, somewhat iron stained, was found in digging a well in the SW. ¼ SW. ¼ sec. 10, T. 10 N., R. 30 W., on George Meador's place. The bed is said to be about 8 feet thick. The same clay is said to occur in many of the wells in this section. It was formerly used for the manufacture of smoking pipes.

A bluish-mottled plastic clay is exposed in the NE. ¼ SW. ¼ sec. 8, T. 10 N., R. 30 W.

Fire clays.—The disintegrated shales exposed in the various localities in the neighborhood of Alma afford a material suitable for the manufacture of articles requiring a clay of rather high fusing point.

Near Fine Spring, in the NE. ¼ SW. ¼ sec. 18, T. 10 N., R. 30 W., the clay is divided into an upper bed of yellow clay, 4 inches thick, overlying a bed of dark-blue clay. The thickness of this blue clay is not known, but it is said to have been dug into by Mr. W. M. James, the owner of the land, to a depth of 7 feet.

This same kind of clay is also found in the E. ½ NW. ¼ SE. ¼ sec. 18 and the NW. ¼ SW. ¼ sec. 17 of the same township and range. The deposit at Fine Spring is in the side of a hill, and is so covered with detritus as not to be visible without digging. This detritus consists for the most part of blocks of sandstone and shaly fragments derived

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from beds overlying the clay. These overlying beds have a thickness of more than 50 feet.

To obtain this clay it will be necessary to resort to mining. The thickness of the material will favor this, and there is an abundance of timber in the neighborhood for mining purposes. It is not possible at present, however, to foresee the depth to which the soft clays may reach before assuming their normal condition as shales. The deposit lies within 2½ miles of Rudy station, on the St. Louis and San Francisco Railroad, and 5 miles from Alma, on the St. Louis, Iron Mountain and Southern Railway. This clay is said to have been tested at St. Louis and at Fort Smith, but no satisfactory information could be gained regarding the parties interested in or making the tests. The dark clay has been tested in the laboratory of the Arkansas Geological Survey for loss in burning. The clay burned to a whitish-yellow color and the loss due to the burning amounted to 9.71 per cent.

Van Buren clays.—The most valuable soft clays at and around Van Buren are those formed by the disintegration of the Carboniferous shales. The localities mentioned below are the ones at which the deposits appear to be most suitable and most advantageously situated for working.

About 3 miles northeast of Van Buren, in the SW. ¼ NW. ¼ sec. 16, T. 9 N., R. 31 W., close to Hendrick's coal opening, is a light-blue clay which burns to a bright yellow. Small test pieces of ware said to have been made from this clay show good, sound texture and a bright yellow color. No definite information, however, could be obtained regarding the parties who made these tests

The bed varies in thickness from 18 inches to 6 feet. The clay was tested for brickmaking purposes at Fort Smith by Pendell & Morrison for Mr. L. D. Middleton. Eleven carloads of this clay were manufactured into 4,500 bricks, which were used by Mr. Middleton to line his limekiln at Fayetteville. The limekiln was kept burning for twenty-seven consecutive days. At the end of that time the bricks were examined and found in perfect order, though highly vitrified. In the manufacture of these bricks Messrs. Pendell & Morrison were troubled by the stickiness of the clay, and in order to work it in their machine were obliged to mix with it the sandy, brownish-yellow clay used in making their ordinary building brick. No definite proportion was observed in the mixture, however, only enough of the sandy clay being added to render the material workable.

Analyses of the clays used in making these bricks are given below.

Analysis of clay from SW. ¼ NW. ¼ sec. 16, T. 9 N., R. 31 W.

[Brackett & Smith, analysts.]

Silica (SiO_2)	64.63
Alumina (Al_2O_3)	24.71
Iron (ferric) oxide (Fe_2O_3)	3.71

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Lime (CaO)	0.31
Magnesia (MgO)	.41
Potash (K_2O)	2.03
Soda (Na_2O)	.94
Loss on ignition	6.52
	102.26
Sand in specimen, very fine	3.43
Water at 110°–115° C	3.02

The following analysis gives the combination of the sandy clay mixed with the above, obtained from Messrs. Pendell & Morrison's brickyard:

Analysis of clay from Pendell & Morrison's yard, Fort Smith.

[Brackett & Smith, analysts.]

Silica (SiO_2)	76.26
Alumina (Al_2O_3)	11.74
Iron (ferric) oxide (Fe_2O_3)	4.54
Lime (CaO)	.39
Magnesia (MgO)	.79
Potash (K_2O)	1.28
Soda (Na_2O)	.98
Loss on ignition	3.82
	99.80
Sand	47.79
Water at 110°–115° C	3.71

The clay from Van Buren is said to have been tested by the Laclede Company at Cheltenham, Mo., and by the Clinton Pottery Company at Clinton, Mo., but the results of these tests have not been ascertained.

On Bridge's place, in the SE. ¼ NW. ¼ sec. 36, T. 10 N., R. 32 W., about 3½ miles from Lily station on the St. Louis and San Francisco Railroad, is a light-blue clay which burns to a yellow.

Mr. Meyers sent some of this clay to St. Louis, where it was made into biscuit ware for decorative purposes. The ware has a bright yellow color. The name of the manufacturer of the ware could not be learned.

Clay from this locality is said to have been tested at St. Louis, by the Clinton Pottery Company at Clinton, Mo., and by Messrs. Sailor & Bevens at Weir City, Kans., the last-named firm having used it for the manufacture of retorts. The analysis is given below.

Analysis of clay from Bridge's place, sec. 36, T. 10 N., R. 32 W.

[Brackett & Smith, analysts.]

Silica (SiO_2)	67.64
Alumina (Al_2O_3)	21.57
Ferric oxide (Fe_2O_3)	2.48
Lime (CaO)	.27

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Magnesia (MgO)	0.62
Potash (K_2O)	1.63
Soda (Na_2O)	.57
Loss	5.53
	100.31

Sand.

Water at 110°–115° C	2.85

The same class of clay is said to have been found in wells in the E. ½ N. ½ SW. ¼ sec. 36, and also in a well 10 feet deep in the E. ½ NW. ¼ sec. 31, T. 10 N., R. 31 W., where it is reported to be 4 feet thick.

An excavation made in the SE. ¼ NE. ¼ sec. 17, T. 9 N., R. 31 W., by J. L. Rea, in prospecting for clay similar to that found on the western side of sec. 16, passed through about 10 feet of Carboniferous shales, but encountered no soft clay.

In digging foundations for a house on Mrs. Moore's farm, near Lees Creek, in sec. 15, T. 9 N., R. 32 W., a fine white clay was discovered under the creek bottom land. On the road from Van Buren to Dora station there are several exposures of yellow clay, in places overlain by red clay. At Mrs. Moore's house and along the northern half of the southeast quarter of the section the red clay overlying the yellow has an average depth of about 2 feet.

In the NE. ¼ SW. ¼ sec. 17, T. 9 N., R. 32 W., a well 10 feet deep passed through 18 inches of fine gray clay at the bottom of the well.

In the SW. ¼ NE. ¼ sec. 30, T. 9 N., R. 31 W., the underlying clay is mottled, and has a thickness of 3 feet. On the east side of the hill on which Mr. Meyers's house is situated a stiff dark-red clay overlies the mottled clay. This red clay is similar in appearance and texture to that in the N. ½ SE. ¼ sec. 15, T. 9 N., R. 32 W.

Near the Van Buren freight depot of the St. Louis and San Francisco Railroad the blue and red clays rest directly upon black shale.

In the SE. ¼ SW. ¼ sec. 18 and the SW. ¼ NE. ¼ sec. 19, T. 9 N., R. 31 W., the railroad cuts expose a brown clay resting upon a mottled red and yellowish-white clay.

Brick clays.—At the western end of the town of Alma there is an area covered by a brownish brick earth showing in places a depth of 5 to 7 feet. It lies in T. 9 N., R. 30 W., in the following sections: SW. ¼ SW. ¼ sec. 5; SE. ¼ SE. ¼ sec. 6; the greater part of E. ½ sec. 7; the west side of sec. 8; and the land extending southward to the creek in the SW. ¼ NW. ¼ sec. 17.

In the SW. ¼ NW. ¼ sec. 17 the brownish-yellow brick earth is underlain by a yellowish-blue clay, which rests upon Carboniferous shale. Both clays contain nodules of iron, which become more plentiful toward the base of the beds.

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From the eastern end of the town of Alma to Dyer station, in sec. 36, T. 10 N., R. 30 W., on the St. Louis, Iron Mountain and Southern Railway, this brownish-yellow brick earth lies on both sides of the railway track. At Dyer it has a yellowish color. It is exposed in the cuts east of Dyer as far as Mulberry.

No bricks are made at Alma. In 1886 two or three kilns were made from the brick earth in sec. 9 for local use by Hon. M. F. Locke. They were hand made and burned to a gray color and are spotted with iron.

The fuel used at Alma is chiefly wood, but coal can easily be obtained from Sullivant's mine, 2 miles from town. Wood ranges in price from $1.25 to $2 a cord, and coal costs $2.50 a ton delivered.

On the west bank of Clear Creek, at the place where it is crossed by the St. Louis, Iron Mountain and Southern Railway, 1¼ miles west of Alma, the following section is exposed:

Section on Clear Creek, near Alma.

Yellow brick clays.
Mottled fawn colored and yellow clay.
Waterworn cobbles.
Black shales of the "Coal Measures."

The yellow and mottled clays of this section aggregate about 25 feet in thickness. These clays become thinner west of Clear Creek.

Bricks were formerly made at Van Buren, but work there has been discontinued. They were manufactured from a brownish clay found lying between the line of the St. Louis and San Francisco Railroad and the shale escarpment to the west. This ground lies chiefly in the SE. ¼ sec. 24, T. 9 N., R. 32 W., and the SW. ¼ sec. 19, T. 9 N., R. 31 W. The clays used for brickmaking are similar to clays in other districts in the western part of the State. The beds are divided by a colored line into an upper and a lower division. The lower division is darker and contains more iron than the upper. This upper division is a light-brown sandy clay and is about 2 feet thick in the vicinity of Van Buren.

CRITTENDEN COUNTY.

Crittenden County lies entirely in the overflowed land of the Mississippi, its surface standing but a few feet above low-water mark along the river. The lowest point along the Kansas City, Fort Scott and Memphis Railroad (Frisco System) between Memphis and Deckerville is 223 feet and the highest point 228 feet above sea level.

The surface of the county is marked by small lakes, abandoned stream channels, and sluggish streams. Near Marion, Grassy Lake, and other places there are deep depressions, doubtless representing former channels of the Mississippi. The one north of Marion is about 1 mile wide and has trees growing in it 3 to 4 feet in diameter. The

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oxbow shape of the depression and its continuation across the country indicate that it is an old river channel and not simply a depression.

The old channel at Grassy Lake is about 1 mile wide and the level of the water is 20 feet or more below the level of the country at Crawfordville.

Most of the soil of the county is composed of sand and silty clay, resulting from repeated overflows of Mississippi River. At no place is the material suitable for making common bricks unless the yellowish surface loam that occurs at a few places near the center of the county may be used for this purpose. Crawfordville and Earl are situated on small ridges which are said to extend in a northeast-southwest direction. These ridges contain at the surface a thin surface loam which is somewhat similar to the yellow loam in the prairie lands west of Crowleys Ridge.

At present no bricks are manufactured in the county.

CROSS COUNTY.

GENERAL GEOLOGY.

Crowleys Ridge extends through Cross County near the center in a north-south direction. The eastern half of the county is a low bottom country traversed by St. Francis River and St. Francis Bayou. Almost the entire area east of the ridge is covered by alluvial deposits. St. Francis Bayou hugs the foot of Crowleys Ridge, which forms a steep erosion scarp across the county.

The geology of the county is best studied along the steep eastward-facing bluffs of Crowleys Ridge. The lower Tertiary strata outcrop at the base of the ridge and extend 65 to 75 feet up its sides; above this comes 18 to 20 feet of waterworn pebbles and coarse sand, which corresponds to the Lafayette of Mississippi and Tennessee, and is but roughly stratified. This in turn is overlain by loess, with a maximum thickness of 50 to 60 feet.

The following is a section along the creek east of Wynne, at a point three-fourths of a mile southeast of the 3-mile post on the railroad:

Section 3 miles east of Wynne.

	Feet.	
1. Loess capping top of hill; in places stratified and containing numerous lime concretions and land shells; lower 5 feet contains sand and pebbles derived from underlying Lafayette...	18	
Unconformity; top of Tertiary.		
2. Coarse oxidized sands and pebbles, which correspond to the Lafayette of Mississippi and Tennessee	18	
3. Gray to lemon-colored sand, with thin layers of pale-gray sandy clay	20	22
4. Brown lignite and lignitic clay.....	1	
5. Clay sand similar to No. 4.....	8	
6. Landslide, which has covered the rest of the hillside to base bluff	30	

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The bed of the creek one-half mile north of the above locality is 65 feet below the top of the Tertiary beds in the above section. The Tertiary strata of the section at the creek for 30 feet above the water, forming a continuous section with the one given above, consist of dark-blue clay interstratified with coarse sand, which contains large iron concretions 1 foot or more in diameter. Besides the iron there are numerous smaller lime concretions. The blue clay where exposed in the bluff sloughs off in large, vertical slabs. It contains more or less mica, selenite, and alum salts. Thickness, 30 to 35 feet.

On the west side of Crowleys Ridge the slope is more gentle and the Tertiary strata are covered by talus from the ridge. The surface material in the adjacent level land is gray to yellowish sandy clay, which is used for brick manufacture. In the town of Wynne this surface clay is penetrated in the wells at a depth of 40 feet.

CLAY DEPOSITS.

The most important clay in the county is the common brick clay. The loess and yellow loam on the top and the west slope of Crowleys Ridge form an inexhaustible supply of common wet-mud and pressed-brick clays.

One mile east of Wynne the following section in the railroad cut shows the variation in the color and character of the loess:

Section in railroad cut 1 mile east of Wynne.

	Feet.
Light-gray to buff loess	10
Reddish loess containing fine sand	20–30
White loess with more or less scattered pebbles and sand	5–10

The reddish loess would doubtless be better adapted to the manufacture of brick than the upper or lower layer. It contains a large amount of iron oxide and would burn to a bright red. Where the calcareous loess is used without mixing it with sandy clays there is great danger of getting the bricks too soft by adding too much water.

There is a bed of good sewer-pipe and tile clay at the base of a section in the Tertiary of Cross County near the village of Cherry Valley. The locality is in the NE. ¼ NW. ¼ sec. 23, T. 9 N., R. 3 E. The clay is exposed in the bottom of the creek to a depth of 3 feet, and extend downward to an unknown depth. It is a fine light-drab clay, unctuous to the touch and apparently suited to the manufacture of sewer pipe. It is more like potter's clay than any other clay that has been found in the Crowleys Ridge country. There is a similar deposit at the base of the section exposed at Double Head Bluff in St. Francis County, near the water level. The locality is in the NW. ¼ NW. ¼ sec. 18, T. 5 N., R. 4 E. It is much thicker here than at Cherry Valley, on the opposite side of Crowleys Ridge, and it is possibly identical with it. Neither of these clays are fire clays and could not be successfully used for fire brick.

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CLAY INDUSTRY.

The plant of the Wynne Brick Company is located at the foot of Crowleys Ridge, about one-half mile east of the station at Wynne. The reworked clay from the ridge is used in the manufacture of brick. Common soft-mud bricks are made, which are pugged and molded by machinery. They are dried under covered racks in the open air. Up-draft scove kilns are used for burning the bricks. The kilns hold from 100,000 to 250,000 bricks. It requires about eleven days to burn the brick, using one-fourth of a cord of wood and one-half ton of coal per thousand bricks. The clay is very easily overburned. Near the eyes in the kilns the bricks are often burned to a vitreous mass, while on the outer edges they are not burned hard enough. The loss in burning and hauling is estimated by the superintendent to be about one-third. The size of the molds used at this plant is 9 by 4¾ by 2½ inches. When burned the bricks measure about 8 by 4 by 2¼ inches.

The water used for the boiler comes from a bored well 250 feet deep. It stands within 100 feet of the surface.

DALLAS COUNTY.[a]

GENERAL GEOLOGY.

Dallas County is in the south-central part of the State, entirely within the Tertiary area. The rocks here, as in other portions of the Tertiary area, are soft, horizontally bedded clays, sands, and brown coals, variously interstratified, the whole overlain by coarse sand and gravel of varying thickness. The northwest quarter of the county is the highest, and from this region the surface slopes eastward and southward. The topography is of the undulating character that is common in regions covered with soft and easily eroded strata.

CLAY DEPOSITS.

CHARACTER OF THE CLAYS.

Potter's, fire, and brick clays are found in Dallas County in practically unlimited quantities. That the potter's clay is of good quality is shown by the fact that the ware made from this clay compares favorably with that made from clays worked at other localities. It has been used locally to a small extent as fire clay in laying up furnaces, etc. It has also been used as a whitewash, and when so used it gives a smooth coat of a pleasing, slightly bluish tint. For such purposes it is dissolved in buttermilk and boiled, and it is claimed that the composition furnishes about as durable a coating as that made with lime.

[a] The matter relating to Dallas County is taken almost entirely from C. E. Siebenthal's report on this county in Ann. Rept. Geol. Survey Arkansas for 1891, pp. 278 et seq.

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It has been found that potteries here can not compete, except in local markets, with potteries that are situated on railways and that work clay equally good. The future of the pottery industry in Dallas County therefore depends on facility of transportation of the product to markets.

CLAY BEDS WORKED.

Since the stratigraphy of these clays has not been worked out in sufficient detail to permit their discussion in natural sequence, it is perhaps best first to describe in detail those beds which have at one time or another been opened and worked, together with those of which the clays have been analyzed, and afterward to take up the miscellaneous outcrops and well records.

Butler clay.—The first clay bed opened in Dallas County was probably that which became known as the Butler bed. This bed is in sec. 4, T. 8 S., R. 15 W., about 400 yards east of the southwest section corner, on the west bank of a head of East Tulip Creek, at an elevation of 350 feet above sea level. Clay has not been taken from this pit for many years, and the only traces of early operations are seen in a hollow that was scooped out of the creek bank and has since filled with débris. In a gully about 100 yards north of this opening 4 feet of lignite outcrops and is overlain by a plastic white clay, similar to Tall's clay, which occurs about one-half mile north of this place. (See p. 76.) Clay was also taken from an old field about one-fourth mile south of the opening first mentioned, but the old pit has long been filled with débris.

Cheatham clay.—The next bed opened was the Cheatham bed, on Dry Tulip Creek, in the NW. ¼ NE. ¼ sec. 22, T. 8 S., R. 15 W. The clay was worked back a little way from the creek on a small drain, but no exposure can now be seen on account of the débris that conceals the bed. On the creek bank about 100 yards south of this locality the following section is exposed at an elevation of 260 feet above sea level:

Section near Cheatham's upper bed, Dry Tulip Creek.

	Feet.
Soil and gravel	2
Argillaceous shale	4
Soft sandstone	3½
Clay and shale	2
Lignite	1
Stiff clay (partly concealed)	4
Lignite	3–4
White, plastic clay	5

Clay has also been taken from a bluff on the west side of the creek one-half mile farther south, in the southwest quarter of the northeast quarter of the same section. The elevation above sea is 255

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feet. From 6 to 8 feet of gray joint clay is exposed. The lignite bed of the upper bank was not observed here, but the upper part of the bluff is covered with débris. The clay is fine grained, with some grit, and clings strongly to the tongue. This clay has been used more extensively than any other in the county and has uniformly been pronounced good by potters.

Bird clay.—The Bird clay bed outcrops on a hillside near one of the small streams flowing from the south into Cox Creek, in the NW. ¼ NE. ¼ sec. 6, T. 7 S., R. 15 W. The same clay outcrops farther west, around the head of Cox Creek, and farther east along the breaks of the hills skirting the north edge of Gum Bottom. The portion of the bed that was worked stands 390 feet above sea level, but clay of apparently the same quality outcrops in places in the drain all the way up to the elevation of 440 feet. This would indicate that the bed is about 50 feet thick. At the pit about 15 feet is exposed. This clay is said to have the disadvantage of being difficult to dry without cracking. This fault could be remedied by a judicious admixture of other clays. When freshly exposed the clay is light bluish in color and very plastic. It is very fine grained and contains but little grit.

Analysis indicates that this is a good clay, the silica and alumina being in good proportion and the percentages of the fluxes very moderate.

Welch clay.—This bed is located in the SE. ¼ SW. ¼ sec. 6, T. 8 S., R. 15 W. The bed stands 355 feet above sea level, making it correspond very closely in elevation with the Butler clay, described above. The bed has been dug into for 7 or 8 feet, and the quality of the clay improved and its color became lighter as greater depth was reached. The clay occurs in angular lumps, is light bluish gray in color, and is very fine grained, with little grit. Mr. Welch reports that the joint spaces are filled with a crystalline substance somewhat resembling common salt, and that particles of this substance become embedded in the ware and make blisters when burning. Samples of ware made from this clay are hard and close bodied. It burns to a gray slate color when perfectly done, the softer pieces varying from yellow to brown.

Mr. Welch reports that he is unable to use the common slip glaze on this clay, for the reason that the heat necessary to melt the glaze melts the ware also, and that he is compelled to glaze with common salt, which, however, is very satisfactory. The ware made from this clay shows to some extent a feature mentioned in connection with the Bird clay—a tendency to crack and warp in the dry house.

Sullenbarger clay.—The Sullenbarger clay bed is in the NE. ¼ sec. 20, T. 8 S., R. 15 W. The clay was used by Lafayette Glass in 1870. Nothing can be seen of the clay used, as the pit has long

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been filled up, but about 200 yards farther north, up the drain, 5 or 6 feet of rather dark gray clay outcrops, and this is reported to be similar to that used. It contains considerable sand, and although not very plastic has a soapy feel when rubbed in a damp state. The ware made from the Sullenbarger clay is thick and somewhat porous. A combination of this clay and the Welch clay was tried by Mr. Welch, who reports that the mixture worked more freely than the Welch clay alone and that there was less liability of cracking in drying or burning. This bed stands 260 feet above sea level. It is difficult to correlate this with any other bed in or near the Cheatham section. No outcrop of lignite was observed near by, nor was any reported in this vicinity. This clay probably comes above the Cheatham section, as the clay supplied came from an elevation of 280 feet. If these beds are to be correlated with any in the Cheatham section, it is evident that the character of the clay changes greatly in the distance between these localities.

Green's clay.—In the SW. ¼ NW. ¼ sec. 5, T. 8 S., R. 15 W., a clay outcrops at an elevation of 440 feet about 100 yards north of Mrs. M. C. Green's, in a small drain that runs west into Tunstle Creek. The bed is about 10 feet thick. The clay is light gray in color, is plastic, has little grit, and clings slightly to the tongue.

The refractoriness of this clay is not very high, yet it is by no means so low as that of the Cheatham clay, which has been very successfully used for pottery. The percentage of sand present is not large enough to be injurious. The analysis of the clay, as well as its physical appearance, indicates that it could be successfully worked into ware.

Tall's clay.—The clay at Mrs. Chloe Tall's place, in the N. ½ SW. ¼ sec. 4, T. 8 S., R. 15 W., at an elevation of 370 feet, is light grayish in color and very plastic and carries a small quantity of rather coarse grained grit. It includes small lighter or white particles.

This clay closely resembles the Bird clay, not only in physical appearance, but also in chemical composition, and will be found suitable for all uses for which the Bird clay is available. For practical purposes the quantity of this clay is unlimited.

Crowder's clay.—W. A. Crowder's clay is in the SE. ¼ NE. ¼ sec. 8, T. 7 S., R. 14 W. About 4 feet of the bed is exposed in the banks and bed of a small drain that flows into Miller Creek at an elevation of about 290 feet above sea level. The clay can be seen only in a weathered condition, but as such it is very tough, plastic, has little grit, and is one of the whitest clays examined.

In refractoriness this clay comes among those so much used for pottery about Benton, Ark., and just below the finest china clay from Cornwall, England, which it very much resembles in chemical composition. There can be no doubt that it is of the best quality.

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The same bed crops out half a mile farther east, and search would undoubtedly reveal it in all the hollows in the neighborhood.

Clarks Creek clay.—In the SE. ¼ sec. 1, T. 8 S., R. 15 W., at an elevation of 280 feet, in the bank of a small drain running into Clarks Creek, there is an exposure of 4 or 5 feet of tough, plastic clay containing scarcely any grit. With the exception of about 1 foot in the middle of the bed, this clay is light gray in color. The middle layer is of lavender color and has a peculiar odor and a sharp, bitter taste.

This very interesting clay deserves a more extended examination than it has been possible to give it in this investigation. In several places within a mile or so of this occurrence, clay of apparently the same quality outcrops at the same elevation, so that there must be almost unlimited quantities of this clay.

Ramsey clay.—The Ramsey clay is exposed about one-half mile east of Ramsey post-office, in the NW. ¼ sec. 9, T. 10 S., R. 13 W. The clay crops out in a drain beside the Fordyce-Princeton road at an elevation of about 265 feet. The bed is exposed to a thickness of 10 feet. The clay is light bluish gray in color and very plastic, and the small amount of grit is very fine grained.

The proportion of alumina and silica in this clay is such that its refractoriness would be high were it not for the injurious amount of fluxes it contains, especially of magnesia, of which it contains more than any of the other clays analyzed. As it is, its refractoriness compares favorably with that of the Welch clay, and it may be used for all purposes for which the Welch clay is suitable. The quantity of this clay is apparently unlimited.

Wormac's clay.—W. L. Wormac's clay bed is in the NW. ¼ NW. ¼ sec. 29, T. 10 S., R. 14 W., at an elevation of 260 feet above sea level. It outcrops to a thickness of 4 feet at the foot of the west bank of Freeo Creek. A small drain empties into the creek at this place, and the clay crops out in this drain up to a spring which is 10 feet above and which probably emerges just above the clay. The clay also forms the bed of the creek for some distance south (downstream). This clay is of a dark slaty blue color, with a waxy luster when freshly exposed, but dries to a dull light drab.

The upper part of the bed, as exposed in the drain, is lighter in color. The clay in the creek bank breaks off in large, roughly rectangular blocks, from which small cubical pieces weather off, leaving a peculiar, angularly indented surface. The clay is plastic and the grit is very fine, being almost imperceptible.

In appearance this clay differs widely from the other clays of Dallas County, and on analysis shows a like difference in chemical composition. The degree of refractoriness is too low to permit its being used as a potter's clay, unless it be as an ingredient in other clays, and it is difficult to see how it could be beneficial as such.

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The resemblance of this clay to some of the Tertiary clays that are used in refining oils is very marked, and its chemical composition is not far different from that of those clays.

Little Cypress Creek kaolin.—This bed crops out in the east bank of Little Cypress Creek, in the SW. ¼ NE. ¼ sec. 26, T. 7 S., R. 17 W., where the following section is exposed:

Section of Little Cypress Creek kaolin bank.

	Feet.
Drab sandy clay, overlain by soil, etc	7
Ferruginous shaly sandstone	½
Drab sandy clay as upper stratum	5
White sandy kaolin	6

The elevation of the base of the section is 320 feet.

The depth exposed does not represent the full thickness of the clay, which forms the bed of the stream and extends to an unknown depth below. It passes into yellow sandy clay 100 yards downstream. How far it extends upstream can not be told, for a few yards above the exposure the outcrop is covered with débris.

In J. E. Amis's well, about three-fourths of a mile farther southeast, a bed of white sandy clay and white sand, 20 feet or more in thickness, was struck at the same elevation. This may represent the kaolin bed. (See section of the well, p. 81.)

In appearance and texture this kaolin clay resembles the commercial scouring bricks, and it was with the thought of utilizing it for this purpose that the sample was collected. When rubbed between the fingers it has a lingering soapy feel, and it was washed and analyzed to test whether this indicated a constituency of kaolin.

In refractoriness this kaolin comes close below the best washed kaolin from Brandywine Summit, Pa., which is used in the manufacture of fine chinaware. In chemical composition, however, this Arkansas kaolin differs widely from the Pennsylvania variety in having more silica and less alumina and water. It is impossible to say what effect this difference in composition will have on the physical behavior of the clay in firing, but, the refractoriness being so nearly the same, the difference in composition will probably have no especially marked effect.

Kilmer kaolin.—A bed of kaolin outcrops on J. R. Kilmer's land in the SE. ¼ SE. ¼ sec. 10, T. 7 S., R. 17 W. A white clay outcrops in the bank of a drain at the elevation of 390 feet. Between 5 and 6 feet of the clay is exposed. It contains a great deal of rather coarse sand and in its natural condition is only slightly plastic. In the dry state the sand easily separates from the finely divided clay mass, which gives a very soapy feel when rubbed between the fingers, indicating the presence of kaolin.

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The analysis shows a kaolin of a fair degree of refractoriness, the water content coming more nearly up to the accepted formula for kaolinite than that in the Little Cypress Creek kaolin. This kaolin will probably be available for the same purposes as the Little Cypress Creek kaolin.

OTHER CLAY BEDS.

The following notes on clay beds, which cover not only outcrops observed, but localities where clay was reported to occur, is inserted here on account of their possible value to prospectors.

In many cases the clay has been described as "sandy." Where this term has been used the sand is usually present in quantity sufficient to overcome the plasticity of the clay, or rather to lower the plasticity below the point at which it is available for ceramic purposes. One remedy for this fault consists in mixing with the sandy clay another clay of higher plasticity. Another remedy consists in washing out the excess of sand, a process that entails so much additional expense that it is impracticable except where the washed product is of a superior quality.

The exposures will be taken up in the order of the townships, beginning at the northeast corner of the county. The elevations are given in feet above mean tide level of the Gulf of Mexico. The elevation given for a well is that of the mouth; the elevation given for a natural section is that of the base.

Township 7 S., range 14 W.—Two feet of white plastic clay outcrops in a gully about 600 yards west of Ivy post-office, and is overlain by 6 or 8 feet of gravel. This is at the same elevation as the Crowder clay, which is less than half a mile distant (see p. 76), and is probably continuous with it. Elevation, 290 feet.

White plastic clay is reported on Gum Creek, in the SW. ¼ sec. 29.

Township 7 S., range 15 W.—In the SW. ¼ NW. ¼ sec. 2, in a gully just west of the Tulip-Sandy Springs road, there is an exposure of 15 feet of clay resting on white sand. The lower 7 or 8 feet is white plastic clay of apparently fair quality. It is possible that the white sand is a sandy kaolin similar to the Little Cypress Creek kaolin. Elevation, 360 feet. (See also p. 78.)

Nancy Jones's well, SW. ¼ sec. 2. Elevation, 390 feet.

Section in well of Nancy Jones.

	Feet.
Soil, gravel, and sand	8–10
White sandy clay	25
Dark clay	25

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Lee Smith's well, NW. ¼ sec. 4. Elevation, 450 feet.

Section in well of Lee Smith.

	Feet.
Soil, gravel, and red sandy clay	20
White sand	5
Tough, dark, sandy clay	25

Outcrop of sandy gray clay, half a mile east of the above. Elevation, 380 feet.

Philip Phillips's well, SW. ¼ NW. ¼ sec. 5. Elevation, 500 feet.

Section in well of Philip Phillips.

	Feet.
Soil, gravel, and sandy clay	15
Sand and clay interstratified	20
White sandy clay	15

Chris. Lawrence's well, northeast corner SW. ¼ NE. ¼ sec. 30. The well was bored and afterward filled up. Reported by S. D. Green. Elevation, 490 feet.

Section in well of Chris. Lawrence.

	Feet.
Soil, gravel, and sand	25–30
Bluish clay (and bottom not reached)	125

This well must pass through the Bird clay, but as it is a bored well no distinction was made between the plastic clay and the sandy white clay, such as is found commonly in the upper part of this ridge.

Township 6 S., range 16 W.—Rice's gin well, SE. ¼ SW. ¼ sec. 36. Elevation, 510 feet.

Section in Rice's well.

	Feet.
Soil, gravel, and yellow sand	20
Bluish white clay, with interstratified beds of yellow sand	28

This is the typical white sandy clay referred to above. The sand constitutes 64.29 per cent of the whole mass.

G. A. Williams's well, NE. ¼ SW. ¼ sec. 36. Elevation, 510 feet.

Section in well of G. A. Williams.

	Feet.
Soil, gravel, and sand	15
Sandy pipe clay	60
Sand below.	

Township 7 S., range 16 W.—J. M. Holt's well, NE. ¼ SE. ¼ sec. 2. Elevation, 460 feet.

Section in well of J. M. Holt.

	Feet.
Soil and gravel	4
Sandy white pipe clay	40

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J. S. Young's well, NE. ¼ SW. ¼ sec. 2. Elevation, 460 feet.

Section in well of J. S. Young.

	Feet.
Soil and gravel	4
Sandy white pipe clay	40
Lignite	1½
Dark-drab plastic clay	38

The lower 38 feet probably represents the Bird clay.

Mrs. E. A. Rice's place, NW. ¼ NE. ¼ sec. 15. White plastic clay nearly free from sand outcrops in the bed of a drain. Elevation, 415 feet.

In the Tulip-Arkadelphia road, about 1½ miles east of O'Neill's mill, there is a bed of dark, putty-colored clay from 20 to 30 feet thick. This clay is very plastic, has little grit, and does not stick to the tongue. Elevation, 520 feet.

Potter's clay of excellent quality is said to have been taken from the creek bank below the old milldam at Willow post-office. The place is now covered with water. Elevation, 340 feet.

Potter's clay is reported in section 14, near the southwest corner, on a drain running into West Tulip Creek. Elevation, 300 feet.

It is also reported that a bed from which Bird used to take clay occurs in section 29, on a drain running into Cypress Creek.

Township 7 S., range 17 W.—J. E. Amis's well, NE. ¼ NW. ¼ sec. 36. Elevation, 360 feet.

Section in well of J. E. Amis.

	Feet.
Red sandy clay and gravel	15
Dark-drab plastic clay	5
White sandy clay and white sand	20

This probably reaches the kaolin that outcrops on Little Cypress Creek. (See p. 78.)

White plastic clay is reported in section 22, in the banks of a small drain, and in section 35, in the bank of Little Cypress Creek.

Township 8 S., range 15 W.—A white plastic clay outcrops in the bed of Canada Creek, just below the ford of the Ivy-Princeton road. Elevation, 250 feet.

A similar clay outcrops in the road a quarter of a mile south of the preceding and 30 feet higher in elevation.

On the Ivy-Princeton road, about three-fourths of a mile north of Princeton, there is an outcrop of very sandy white clay. Elevation, 260 feet.

In a gully beside the road in the NE. ¼ NE. ¼ sec. 21 there is a bed of bluish-white joint clay from 2 to 3 feet thick. This clay has little grit and does not cling to the tongue. It passes into sand to the

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north and into jointed and indurated sand of the same color 20 feet to the south. The joint cracks of the clay have been filled with sand carried by percolating waters. Elevation, 280 feet.

John C. Welch's well, in the NE. ¼ NW. ¼ sec. 19, passes through about 30 feet of white sand. It may be that this is a sandy kaolin similar to those described in the preceding pages. Elevation, 350 feet.

An outcrop of plastic gray clay occurs in the road about 400 yards east of Welch's pottery. The thickness of this bed was not apparent. Elevation, 440 feet.

There is said to be a fine bed of excellent potter's clay on a small stream north of Princeton, about 1 mile above a point where the stream is crossed by the Malvern road, 1 mile north of the town.

John C. Welch's clay bank, in sec. 17, T. 8 S., R. 15 W., is in a neighborhood that abounds in excellent clays. The beds occur also along both sides of Cypress Creek and of West Tulip and East Tulip creeks, near to the headwaters of those streams, winding in and out among the hills and cropping out in the bluffs and banks of streams. The covering of the beds varies greatly; where the overlying beds have been eroded away the covering is thin, but where they crop out in steep-sided hills it is generally thick. Where these clays have been dug they have been taken from beneath rather heavy coverings.

Mrs. Lantorn's well, sec. 17, 440 yards west of the northeast corner. Elevation, 310 feet.

Section in well of Mrs. Lantorn.

	Feet.
Soil and gravel	6
White pipe clay	10
White sand	2
White clay	27

A load of this clay was tried by Mr. Welch, who says that it works very well.

P. N. Lantorn's well, SE. ¼ NE. ¼ sec. 8. Elevation, 370 feet.

Section of well of P. N. Lantorn.

	Feet.
Soil and gravel	2
Hard bluish clay	58
Lignite	8

L. D. Lantorn's well, sec. 5, middle of the south side. Elevation, 480 feet.

Section of well of L. D. Lantorn.

	Feet.
Soil, gravel, and sand	10
White pipe clay	28

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Mrs. M. C. Green's well, SE. ¼ NW. ¼ sec. 5. Elevation, 480 feet.

Section in well of M. C. Green.

	Feet.
Soil and gravel	8
White pipe clay	8
Bluish clay	27
Black "rock"	½
Lignite	3
Sandy bluish clay	30

A. Whitener's well, SE. ¼ NW. ¼ sec. 3. Elevation, 480 feet.

Section in well of A. Whitener.

	Feet.
Soil, gravel, and sand	15
White clay	1
Lignite	1
White plastic clay	14

This lowest clay outcrops in a gully 50 yards west of the house.

Township 8 S., range 17 W.—D. Ratliffe's well, SE. ¼ SE. ¼ sec. 2. Elevation, 290 feet.

Section in well of T. Ratliffe.

	Feet.
Soil and red clay	4
White plastic clay	30
Dark plastic clay, with ferruginous sandstone particles	10

There are scattering leaf impressions in both the light and the dark clays.

Bernard Dellamar's place, SW. ¼ NW. ¼ sec. 14. An exposure of 12 feet of dark bluish drab clay. This clay is plastic and has little grit. Elevation, 310 feet.

Outcrop of 15 feet of light-blue plastic clay beside the road in the NW. ¼ sec. 15. This clay weathers very much like the olive-green Tertiary marl. It contains somewhat more grit than the clay that is most used for ware in this country. Elevation, 320 feet.

J. R. Porterfield's well, SE. ¼ NE. ¼ sec. 17. Elevation, 350 feet.

Section of well of J. R. Porterfield.

	Feet.
Soil and gravel	17
Sand	1
Dark, soft, plastic clay, with lignite flakes and nodules of iron pyrites.	16

Potter's clay is reported near the center of sec. 34; also near the northeast corner of sec. 27 and in the SE. ¼ of sec. 35.

A well in the NW. ¼ NW. ¼ sec. 36 passes through 75 feet of sand with lumps of plastic clay and ends in white sandy clay similar to that overlying the lignite bed in this region. Elevation, 280 feet. These lumps of clay are at many places embedded in the sandy strata, and have been reported in several wells.

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Township 9 S., range 14 W.—Pottery clay is reported in the SW. ¼ SE. ¼ sec. 32, and in SE. ¼ SE. ¼ sec. 30.

Township 9 S., range 15 W.—From 2 to 4 feet of bluish-white plastic clay outcrops in a gully beside the road in the SE. ¼ SE. ¼ sec. 34.

In the bank of Hays Creek, SE. ¼ NW. ¼ sec. 5, there is an outcrop of about 15 feet of grayish joint clay with considerable sand. Elevation, 220 feet.

Potter's clay is reported in the NW. ¼ SW. ¼ sec. 18; also on Sand Creek, in the NW. ¼ sec. 20.

Potter's clay is reported on the Bowers place, near the center of sec. 22.

Clay which was pronounced good is said to occur in the SW. ¼ SW. ¼ sec. 6.

Grayish-green potter's clay, 10 to 12 feet thick, outcrops on the Princeton-Dalark road, in sec. 11.

Township 9 S., range 16 W.—C. C. Williams's well, NE. ¼ NE. ¼ sec. 18. Elevation, 290 feet.

Section in C. C. Williams's well.

	Feet.
Soil and gravel	8
White pipe clay	20

Township 9 S., range 17 W.—Frank Russell's well, SW. ¼ sec. 1; 15 feet of plastic clay in bottom. Elevation, 290 feet. The same clay outcrops in a spring a few yards north of the well.

Where the Fordyce-Princeton road ascends the hill at Dallas Stell's ("Stony Point"), just north of Cooks Creek, in the S. ½ sec. 18, T. 10 S., R. 13 W., halfway up the hill, is a 10-foot bed of clay which may prove valuable for pottery, though the best of the clay may be only that near the surface, which is most affected by weathering. It is possible that it is thicker than 10 feet, for the limits of the bed are not well defined.

A well dug about 1,500 feet north of Dallas Stell's house penetrates lead-colored sands with leaf impressions, and it is possible that the clay on the hillside south of the house may be the weathered edge of this sandy stratum.

Through the region traversed by the Fordyce-Princeton road many of the surface clays are well adapted for pottery, but they all contain some pebbles and would need to be screened or passed through a machine to remove these.

Many exposures of stratified beds of pottery clay have been observed along the road south of Princeton, but the region is thinly settled and it is not possible to give the land divisions on which they were found. They vary greatly in thickness, though it is probable

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that many of the beds which appear to be but 2 or 3 feet thick are much thicker, and that only small portions of them are exposed.

On the road leading from Princeton to Fordyce, about 1½ miles south of the point where the Fordyce road leaves the Camden road, a 10- or 12-foot bed of pottery clay is exposed in a gully beside the road.

The road from Tulip to Dalark passes over several beds of pottery clay. They crop out, among other places, in secs. 15 and 16 of T. 8 S., R. 17 W., on the lands of George Elders, about 4 miles east of Dalark, where they are overlain by red clayey sands.

A light-colored pottery clay outcrops in the gully east of the road in the NE. ¼ NE. ¼ sec. 20.

Township 10 S., range 14 W.—White plastic clay is reported in the NW. ¼ NE. ¼ sec. 5 and the NW. ¼ NW. ¼ sec. 7.

A. B. Smith's well, SE. ¼ sec. 8. Elevation, 265 feet.

Section in well of A. B. Smith.

	Feet.
Soil, red clay and gravel	12
Bluish joint clay	40
Red sandy clay	8

This clay evidently passes into sand, for a well at the same elevation 100 feet away shows:

Section in well in SE. ¼ sec. 8, T. 10 S., R. 14 W.

	Feet.
Soil and gravel	12
White fine-grained sand	33

Potter's clay occurs in the SE. ¼ sec. 8. Ten feet is exposed in the road and in the banks of a stream that flows into Freeo Creek. Elevation, 250 feet.

Potter's clay outcrops in the Little-Bay Princeton road in the SW. ¼ sec. 16. Elevation, 265 feet.

Smith place, SE. ¼ NW. ¼ sec. 17. Two or three feet of white plastic clay is exposed in the bank and bed of Freeo Creek, immediately above the ford. Elevation, 230 feet.

R. H. Barner's well, NE. ¼ NE. ¼ sec. 20. Elevation, 275 feet.

Section in R. H. Barner's well.

	Feet.
Red clay and sand	7
Blue joint clay, sandy toward bottom	34

Between 10 and 15 feet of grayish pottery clay outcrops in the road in the NW. ¼ sec. 34. Elevation, 270 feet.

Township 10 S., range 15 W.—In a gully beside the road, north of a church in the NW. ¼ sec. 2, is an exposure of 8 to 10 feet of bluish-white plastic clay. Elevation, 235 feet.

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J. T. Shankle's well, SW. ¼ NW. ¼ sec. 7. Elevation, 300 feet.

Section in well of J. T. Shankle.

	Feet.
Red sand and clay	20
White pipe clay	10
Dark lumpy clay	10

A bored well at the same elevation showed 22 feet of the dark clay and stopped in lignite. The dark clay contains a few leaves.

J. W. Richardson's place, SE. ¼ SE. ¼ sec. 9. Ten feet of gray plastic clay outcrops beside the road. Elevation, 240 feet.

Potter's clay 15 feet thick outcrops in a gully in the SE. ¼ SW. ¼ sec. 16, and is underlain by 10 to 20 feet of white sand. Elevation, 260 feet.

Potter's clay is reported in a well at the gin in the NW. ¼ SW. ¼ sec. 18.

Pottery clay outcrops in the road in the NW. ¼ sec. 21. Elevation, 260 feet.

Potter's clay is reported in the NW. ¼ sec. 22.

Township 10 S., range 16 W.—W. M. Walsh's well, NE. ¼ NW. ¼ sec. 1. Elevation, 265 feet.

Section in well of W. M. Walsh.

	Feet.
Red clay and sand	8
Black clay with leaf impressions	10
Yellow sand and clay	45
White plastic clay	4

Well stopped in the last stratum without passing through it.

On Peterson's place, NE. ¼ SW. ¼ sec. 12, a foot of light-colored clay with some grit is exposed in a drain. Elevation, 230 feet.

James Goodgame's well, NW. ¼ NE. ¼ sec. 13. Elevation, 240 feet.

Section in well of James Goodgame.

	Feet.
Soil	4
Pipe clay	17

R. E. Hogg's well, SW. ¼ SE. ¼ sec. 13. Elevation, 310 feet.

Section in well of R. E. Hogg.

	Feet.
Soil and gravel	10
Potter's clay	2–3
Sand below.	

CONCLUSIONS.

The geologic structure of the region and the known outcrops of potter's clay lead to the conclusion that such clays exist in great abundance and of excellent quality in Dallas County. Their wide-

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spread distribution on both sides of East Cypress and Cooks creeks and of West and East Tulip creeks has already been mentioned. In addition to the places at which good clays are already known, there is no doubt that they will also be found on the west side of Moro Creek and on the higher lands skirting the west side of Saline River in Dallas County.

ANALYSES OF CLAYS.

Analyses of clays in Dallas County are given in the following table:

Analyses of Dallas County clays.

Clays analyzed.[a]	Silica.	Alumina.	Ferric oxide.	Titanic oxide.	Lime.	Magnesia.	Soda.	Potash.	Loss on ignition.	Sand in air-dried clay.
Cheatham clay	72.82	13.72	1.267	2.54	0.63	0.75	1.08	0.96	5.76	50.30
Bird clay	66.42	21.19	1.956	1.02	1.13	.82	1.26	.....	7.76	37.28
Welch clay	71.27	16.86	2.378	1.75	.73	.77	.46	.44	6.54	30.50
Green's clay	68.03	17.19	3.589	1.49	.81	1.00	.54	1.00	6.31	35.80
Tall's clay	62.343	20.631	4.062	1.556	.173	.668	.325	.729	9.339	16.73
Crowder clay	66.336	18.966	2.008	1.869	.256	.225	.800	.379	8.130	17.23
Clarks Creek clay	50.653	25.450	6.481	2.591	.167	.604	.242	.742	13.100	3.46
Ramsey clay	60.700	21.567	5.000	.447	.469	1.583	.297	1.526	8.608	15.25
Wormac's clay	64.734	16.569	3.796	1.234	.837	1.535	1.395	1.685	7.334	25.14
Little Cypress Creek kaolin	62.166	26.096	.341	1.302	.051	Trace.	.252	.364	9.067	67.94
Kilmer kaolin	52.269	32.207	1.781	1.505	.066	.028	.341	.271	11.170	38.57

[a] The exact locations of the clays are stated in the preceding pages.

Of the preceding eleven analyses the first four were made by W. C. Riley and the remaining seven by L. R. Lenox. It will be noticed that the clays analyzed by Doctor Riley show a much higher percentage of sand than those analyzed by Professor Lenox. The determination of the percentage of sand is at best only approximate and is a matter of individual judgment, and this accounts for the different percentages found. In two clays, which have to all appearances an equal amount of sand, the percentage of sand in the one as determined by Doctor Riley is about twice as great as the percentage in the other as determined by Professor Lenox. In comparing the sand contents of the clays this should be borne in mind.

Each of the clays analyzed contains a considerable amount of titanic acid and smaller quantities of sulphuric and phosphoric acids. Neither of these substances is taken into consideration in the formula devised by Bischof for calculating the refractoriness of clays, so that in determining the refractoriness of the clays analyzed these constituents have been disregarded. It is highly probable, however, that they exert some influence on the fusing point of clays.

Several of the clays showing the largest percentages of titanic acid were washed and their coarser and heavier parts were examined under a microscope. Owing to the fragmentary condition of the particles it was not possible to identify any of them except the quartz.

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CLAY INDUSTRY.

At present no plants are reported as engaged in the manufacture of clay products in Dallas County. The pottery industry of the county has been mainly confined to the operations of the Bird brothers and their apprentices. The first pottery was established by them, and the last active pottery in the county was owned and operated by John C. Welch, who learned the potter's trade under William Bird.

The first pottery was set up in 1843 by two of the brothers, Joseph and Nathaniel Bird. In 1844 James Bird, another brother, erected a pottery just over the county line, in Grant County, in the SE. ¼ SE. ¼ sec. 23, T. 6 S., R. 16 W. He had burned but a few kilns when he sold out, and the business was discontinued. He used clay from a bed close by the old shop.

William Bird started his first pottery in 1843, in the SW. ¼ NW. ¼ sec. 7, T. 7 S., R. 15 W. His clay came from the Butler bed. He continued steadily at work here until 1851 or 1852, when he moved his shop to the site now occupied by John C. Welch's pottery, in the NW. ¼ SW. ¼ sec. 17, T. 8 S., R. 15 W. He operated this pottery until 1861, when he sold out to Welch. While running here he used clay from the Butler bed, and later from the Cheatham beds also. Bird started another pottery at the close of the war on what is known as the Bird place, in the SW. ¼ NW. ¼ sec. 6, T. 7 S., R. 15 W. He continued here until about 1881, when he left the State. He afterward returned and followed his trade in Malvern. While at the Bird place he used clay from the Butler bed; also from the Bird bed, on the Bird place, and from Gum Bottoms. Bird has the reputation among the older inhabitants of the county of making very fine, durable ware.

John C. Welch, as before noted, learned the trade under William Bird, and in 1861 bought him out and continued the business at the same place. The capital invested, exclusive of that for location, was about $150. The kiln had a capacity of 1,500 gallons. Two wheels were run and the average annual output was 10,000 or 15,000 gallons. The product was in the form of jugs, jars, churns, and crocks, which found a market in neighboring towns—Pine Bluff, Camden, Warren, Monticello, Eldorado, Magnolia, and other places. Mr. Welch at first used clay from the Cheatham beds, but later found and worked the Welch bed. His ware was hard, close-bodied, and thin.

Nathaniel Culberson worked awhile with Welch, and between 1858 and 1865 ran a pottery near the middle of sec. 24, T. 8 S., R. 15 W. He used clay from the Cheatham beds. Fragments from the old kiln show a rather thick, porous ware.

In 1859 or 1860 a foreigner named Etl established a pottery about three-fourths of a mile north of the preceding and operated it for about three years. Besides ordinary crockery he made flower pots

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with vines and flowers in relief on the sides. He used clay from the Cheatham beds.

In 1870 Lafayette Glass, after learning the trade under Welch, set up a pottery in the NE. ¼ SE. ¼ sec. 29, T. 8 S., R. 15 W. He operated here for a year and then removed to Benton and became the pioneer potter of that place. While in Dallas County he used clay from the Sullenbarger bed.

Between 1874 and 1876 E. A. Munn, a brother-in-law of Welch, ran a pottery in the NE. ¼ SE. ¼ sec. 12, T. 8 S., R. 16 W. He left there and established a pottery at Malvern. He used clay from the Welch bed. Fragments about the old kiln show a fine, hard, and close-bodied ware.

DREW COUNTY.

GENERAL GEOLOGY.

The surface soils of Drew County consist either of disintegrated Tertiary (Eocene) rocks, which underlie the whole county, or of a thin coating of gravel of later age on the Tertiary beds. The flood plains of some of the streams are of recent alluvial origin, while those of others are made of older clays. Nearly all the lands east of Hurricane Creek are alluvial. Excellent brick clays are abundant about Monticello, though some of the surface clays contain a few pebbles, and others contain iron nodules. In the western part of the town of Monticello about 30 feet of purple and mottled Tertiary clay are exposed in gullies and in the railway cut. The purple clays crack in drying and, in their present condition, are not available for brick-making. These beds are exposed in places for 2 miles west of the town of Monticello.

A well bored by Emil Boechardt at Monticello in 1889, on the southwest corner of sec. 35, T. 12 S., R. 7 W., passed through the following strata. as reported by Mr. Boechardt:

Section in well of Emil Boechardt.

	Ft.	In.
1. Loam		4
2. Red clay	5	6
3. Pipe clay and sand	15	
4. Dark clay with shells	50	
5. Sandstone		6
6. Dark clay with shells	88	6
	159	4

A sample of clay No. 6 of this section was examined by the Arkansas Geological Survey. It is a dark, fine clay with a little mica and a few fragile fossil shells of Tertiary age. It does not crack on drying, and if the beds are accessible and could be found without shells it would make a good potter's clay and would be available for the

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manufacture of good fire bricks. It is probable that other Tertiary clays that underlie Drew County might, by washing, be made available for the manufacture of pottery.

At Cornish Ferry, on Saline River, a section of the Tertiary beds is exposed, having at the base a dark lignitic clay that resembles some of the pottery clays of Saline County.

CLAY INDUSTRY.

In the town of Monticello the Drew Brick Company and a plant operated by J. H. Blythe are engaged in the manufacture of common building bricks.

FAULKNER COUNTY.

GENERAL GEOLOGY.

The geology of Faulkner County is merely a repetition on a somewhat larger scale of that of the western part of White County. The rocks have been thrown into great folds and then worn away, but the folding has been, on the whole, so simple and the alternation of the sandstones and shales has been so regular, that the geologic structure of the county is easily interpreted. When this structure is understood the distribution of the clays and clay shales in the county will be readily comprehended.

The rocks of this region belong to what are commonly known as the "Barren Coal Measures." They are sandstones and shales, across which run occasional veins of quartz, and on the upturned edges of which there are patches of bog iron deposited by chalybeate springs. Locally the sandstones and shales are somewhat calcareous, but these calcareous places are only thin bands or small patches and are of little or no importance except that some of them contain fossils.

The rocks of the county are all sedimentary, having been deposited originally in horizontal layers in water. After their deposition these sediments were consolidated by the pressure of thick beds that were deposited on top of them. In the course of time they were subjected to horizontal pressure from the south and thrown into a series of parallel folds, and, rising above the water, they formed dry land. After this elevation they were acted upon by weathering and eroding agencies, the former breaking up the rocks (for these sediments, originally sand and mud, were already hardened by long pressure to sandstone and shale) and the latter washing the fine material away. But as rocks are not all equally soluble or equally acted upon by decomposing and weathering agencies, and as they are not all transported with the same facility after disintegration, some of these rocks in Faulkner County have been removed much more rapidly than others. Thus rocks which long resist decay and removal—that is,

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the sandstones—stand out now as hills and ridges, while eroding agencies have scored valleys in the softer and more easily affected rocks—that is, the shales. As the rocks of this region are alternate sandstones and shales, the topographic result of this condition and action is a series of parallel valleys and ridges, running, as a rule, east and west across the county.

As a rule the axes of these rock folds are not horizontal but are a little lower at one end than at the other. From this dipping of the

FIG. 7.—Diagram showing relations of structure to topographic relief in Faulkner County. *sh*, Shale; *ss*, sandstone; *aeb*, valley; *c*. *o*, stream piracy; *e*, watershed.

folds it results that the ridges, instead of being everywhere straight, curve around and cross the lower ends of the axes of the folds. This will be understood by reference to the accompanying diagram (fig. 7).

It will be understood from this also that the valley *aeb* is one

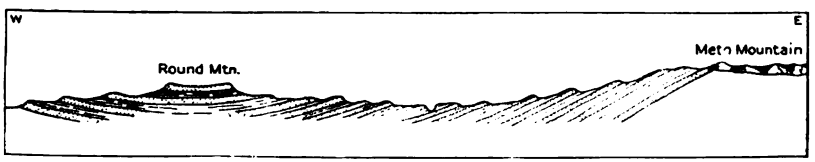

FIG. 8.—East-west section through Round Mountain and Meto Mountains, Faulkner County.

and the same geologically, although it may be divided at *e* by a watershed, or the ridge may be broken at *o* and *c*. It should also be noted that the shales that dip westward at *a* dip northward at *e*,

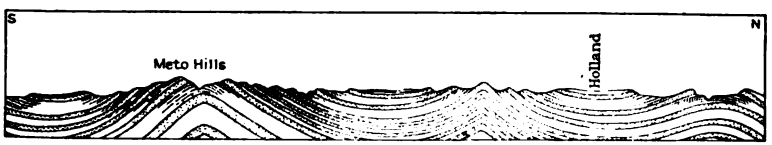

FIG. 9.—North-south section through Meto Hills.

and the same bed would dip southward on the south side of the axis of the fold.

Fig. 8 is an east-west section along the summit of Meto Mountain (a group of parallel ridges about 5 miles wide lying just north of Faulkner Gap) and across the summit of Round Mountain to Arkansas River.

A north-south section across the Meto Hills to a point about 3 miles north of the town of Holland is given in Fig. 9.

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These details are sufficient to give a pretty clear idea of the geology of Faulkner County with reference to the occurrence of the clays and clay shales. The shales form the valleys of the region; the sandstones form the ridges. The shales are seldom seen at the surface, being covered usually by residuary material of one or another kind. At many places, especially in the lower valleys or "slashes," the surface soil is a "buckshot clay."[a]

About the bases of the sandstone ridges the débris from the hillsides—blocks of sandstone and sandy red clays—cover the outcrops. The shales are almost invariably found in digging wells, so that the people have an idea that the shale or "slate," as they generally call it, lies close to the surface all over the county. This appears to be the case, because the wells are usually dug in the valleys and the valleys are carved in the shales. This will be understood from the accompanying figure, which shows the geology of the region about

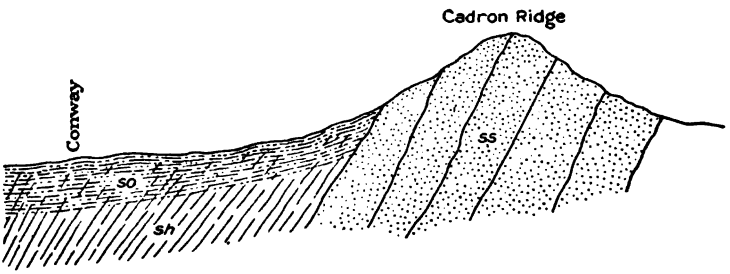

FIG. 10.—Section showing the relations of the shales of the valley to the loam and soil about Conway. *so*, Soil; *sh*, shale; *ss*, sandstone.

Conway with relation to the shales, the decayed shales, and the soil of the valley to the sandstone on Cadron Ridge, a short distance north of the town.

CLAY DEPOSITS.

The clays and clay shales of Faulkner County are of four kinds—(1) clay shales; (2) limonitic buckshot clays; (3) leached clays along the bayous and in the slashes; (4) alluvial and sandy chocolate clays skirting the bottoms of Arkansas River and in some places extending far up its affluents from this county, such as the Cadron.

CLAY SHALES.

With the preceding explanation of the geologic structure the distribution of the clay shales may be readily understood. They lie in the valleys everywhere in the county. Of course there are lowlands, like the alluvial plains of Arkansas River, made up to a considerable depth of river silt, clay No. 4 of the above list, sand, and gravel, to

[a] For the discussion of the buckshot clays see p. 28.

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which this statement is not intended to apply. The alluvial materials that have filled the valleys of some of the other streams have also buried the shales to a considerable depth. These are not the places, however, in which one would expect to find the clay shales accessible for practical purposes. Indeed, while the valleys have shales of great thickness, the rocks are usually at too low an elevation to permit advantageous exploitation, on account of the expense of lifting the material from shafts or other openings and of draining these openings. Crude material to be cheap must be easily accessible and must therefore be sought on high ground, where the locality facilitates exploitation and avoids the necessity of draining the pits. There are several shale hills and ridges in the county where these conditions are favorable, and if one observes the geologic section north and south across the county it will be seen that these places are most likely to occur on the axes of the synclinal folds. One of these hills is known as Round Mountain, and is located in secs. 11 and 14, T. 5 N., R. 12 W., about on the axis of the Conway syncline. This little mountain stands about 250 feet above the general level of Cypress Valley and is in every respect similar to one having the same name in White County, which is located, like this one, on the axis of the Conway syncline. The rocks here are nearly horizontal, dipping gently to the south beneath the mountain, which is capped by a bed of sandstone that has preserved what remains of it from complete destruction. The total area covered by this mountain is about one-half a square mile.

Samples of the shale from this mountain have not been analyzed, but samples from the same beds in Round Mountain of White County have been analyzed and it is probable that they have the same or approximately the same composition. These analyses are given on page 224.

No coal has been found in the Faulkner County mountain, but the existence of a 2-foot bed of coal in the White County mountain warrants the supposition that there may be a similar bed in this one also.

Just west of Round Mountain is another though somewhat smaller hill, which has no local name. This hill has the same geologic structure as Round Mountain and is composed of the same kinds of rocks, which lie in the same position. It stands in sections 15 and 16 of the same township and covers an area of about 160 acres.

The other synclines in which the argillaceous shales abound are the Holland syncline, the Greenbriar syncline, and the Cato syncline. The shales of the Holland syncline are exposed in the Conway-Greenbriar road in sec. 13, T. 6 N., R. 14 W., where the road crosses East Cadron Creek. The body of the ridge just north of the creek at this place is of clay shale, and the whole is capped by sandstone. The ridge extends a mile to the west of the East Cadron bridge, but to the east it bends gently toward the south to sec. 15, T. 6 N., R. 12 W.,

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where it curves abruptly northward, passes to the east and north of the village of Holland, and, bending upon itself, passes westward by Linden post-office.

This syncline is topographically highest at its western end, where the hills stand about 150 feet above the valley, and it sinks gradually to the east. The shales forming the body of this elevated syncline are well above water level, and as they are nearly flat there would be no difficulty in mining them. Their distance from the railway, however, will doubtless prevent their being utilized for the present.

Horseshoe Mountain, near Greenbriar, stands on the axis of the Greenbriar syncline. This mountain, like the other synclinal ridges, is composed mainly of argillaceous shale and, like them, is capped with a protecting bed of sandstone. It rises abruptly from the Greenbriar Valley, above which its summit stands about 300 feet, but sinks to a level about 100 feet above the Cadron. These shales, while available in so far as their composition, abundance, and geologic and topographic disposition are concerned, are too far from railway transportation to be of immediate use for manufacturing purposes.

Frenchman Mountain marks the axis of the Cato syncline. It is about 250 feet high at its east end, about a quarter of a mile west of the town of Cato, but becomes lower toward the west. The axis of this syncline dips toward the west, so that the mountains open westward, and the axis crosses the St. Louis, Iron Mountain and Southern Railway near Mayflower station.

The heavy beds of argillaceous shale forming the base of Frenchman Mountain are protected by the usual sandstone bed. This locality is several miles from the railroad.

The so-called Round Mountain group of ridges, lying between Preston station and Arkansas River, is made up of alternate beds of sandstones and shales that set one in the other like a nest of saucers. Many of these basic shales are adapted to the manufacture of pipes and paving bricks, but they have never been utilized. The less basic beds are available for the manufacture of refractory goods. They all occur in the greatest abundance, well located topographically, of good quality, and convenient to the St. Louis, Iron Mountain and Southern Railway.

Clays derived directly from shales by decomposition are common over much of Faulkner County, but as a rule they are so concealed and so irregular in distribution that but little can be said of them. They are to be sought on the upturned edges of the clay shales where these rocks have broken down under disintegrating influences, and as the sandstones usually form the hills and ridges and the shales the valleys, these clays are to be looked for chiefly in the valleys, between the sandstone ridges. Such clays are often spoken of by the people as "rotten slate." They are abundant at the bases of some hills of shale

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where the shale talus has been broken up by long exposure to percolating waters.

Some of these clays are available for making rough pottery, such as jugs, crocks, and churns, or for making vitrified bricks or sewer pipes. The deposits are generally too small, however, to be of much importance.

LIMONITIC BUCKSHOT CLAYS.

The ordinary buckshot clay—that is, the clay containing small nodules or concretions of iron—occurs over half of Faulkner County. It is most abundant in the valleys and over the flat portions of the uplands of the county, and is least abundant on the crests of sharp ridges and in the alluvial bottoms of the Arkansas. Where it is near the sluggish bayous, and is overflowed for many days and even weeks each year, waters charged with organic matter have leached the iron from its upper portion, leaving it in places a clean, white potter's clay. This same process, operating on a minor scale, has produced the yellowish or ash-colored loam that forms the surface soil over a large portion of the county. From this loam most of the bricks of Faulkner County are made.

Beneath this more earthy surface there is generally an irregular bed or band of nodules of limonite iron that renders the clay difficult to manipulate, especially when the bricks are handmade, and produces the dark chocolate and spotted color so common in bricks from such soils.

The limonitic buckshot clay is so widely distributed in Faulkner County that it may be said to form the agricultural soil of three-fourths of the county. It is doubtless thickest in the valleys, in nearly all of which it covers large areas. It is in the "slashes," however, or wherever the ground is flat enough to prevent quick drainage, that it occurs in its most characteristic forms.

Throughout the Cypress Valley, from the Arkansas bottoms to the eastern border of the county, the buckshot limonitic clays are concealed only by the thin surface soil, which is in reality but a part of the blanket of clay soil that covers the whole region. The same is true of all the other valleys of the county, but especially of those in which there is slash land, or over which the drainage is sluggish. About Conway, Greenbriar, Holland, Enolia, and Amsteadville these clays are abundant, and are everywhere available for making such bricks as are usually made of the limonitic clays.

LEACHED CLAYS.

The leached clays are but one phase of the buckshot clays, being the upper soils from which the iron has been removed by acidulated waters. As a rule the longer the water stands on the ground the

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more thoroughly is the iron leached from the soil, and it is by this process that the leached lead-colored clays are formed. Such clays are therefore most common along the sluggish streams that readily overflow their banks and spread out over wide, marshy bottoms, such as Palarm Bayou, East Cadron Creek, and Bayou Meto. And it is over the flood plains of these streams that the leached clays are most abundant; not, however, in the valleys only, but wherever the conditions for their formation are favorable.

The leached clays are available for the manufacture of the common grades of pottery, such as jugs, crocks, jars, and milk pans, but as their exploitation is not so easy as that of the Tertiary potter's clay of the southwestern counties of the State, they can scarcely compete with those clays. and can therefore be of slight and local importance.

CHOCOLATE CLAYS.

The chocolate-colored clays in some places form what are known as the "rich buckshot lands"[a] adjoining the river bottoms. They are usually too sandy to be useful for manufacturing purposes. In places they are very "fat." They are not everywhere of chocolate color, for wherever they contain much organic matter they have become black from the mixture of the organic matter with the lime with which this clay is at most places freely charged. Some of the richest agricultural lands of the State are on these chocolate clays. They are not known to have any value for manufacturing purposes.

CLAY INDUSTRY.

The Cypress Valley region about Conway[b] is covered by a yellowish clay, mottled here and there with light-gray patches. These gray patches are generally of small area and not very thick. In texture the gray clay resembles the yellow, although it has somewhat different qualities when manufactured. The upper portion of the yellow clay, from which the bricks are usually made, is of a light-yellow color, is generally about 2 feet in thickness, and is comparatively free from iron nodules. The lower division, from 24 to 30 inches thick, is of much darker color, and contains a great quantity of iron nodules ranging in size from that of a pin head to that of a walnut. This lower clay is not much used for brickmaking. The bricks made from it are stronger, harder, and more durable than those made from the upper clay, but they do not look so well.

The clays just mentioned are underlain everywhere throughout this district by a black argillaceous shale, which is more or less fractured near the surface, becoming harder and more compact as

[a] Not to be confused with the limonitic buckshot clays

[b] The notes on the brick industry at Conway were prepared principally by William Kennedy.

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they are penetrated. The upper layers of this shale at some places break into kidney-shaped pieces, which shell off concentrically.

A well at John McCullough's old brickyard, in the NE. ¼ NE. ¼ sec. 1, T. 5 N., R. 14 W., gives the following section:

Section at John McCullough's old brickyard.

	Feet.
Light-yellow clay used for bricks	2
Dark-yellowish clay, brown below, and containing iron nodules	2
Broken black shale	3
Hard black shale at bottom of well.	

On the northeast corner of block 42 of the town of Conway, about 1 mile southwest of McCullough's old yard, in a well about 200 yards east of Mr. Firestone's brickyard, the shales appear at a depth of a little over 3 feet. In Firestone's pits the clay used does not exceed 2 feet in thickness. This clay is darker than that formerly used by McCullough and contains more iron nodules.

The bricks are gray in color, and where the two clay beds have been mixed the bricks are spotted. In the arch they have a tendency to melt at the ends.

Secs. 18 and 19 and 7 and 8, T. 4 N., R. 14 W.; secs. 10, 11, 12, 13, 14, 15, 22, 23, 24, 25, and 26, T. 5 N., R. 14 W.; and secs. 6, 7, 18, 19, 30, and 36, T. 5 N., R. 13 W., are covered by yellow clay similar to that around Conway.

Mr. Firestone made common bricks by hand until 1902, when he installed a machine run by steam. He now makes a stiff-mud end-cut brick. The clay is tempered and molded in a No. 7 special plunger machine, dried in the open air, and burned in clamp kilns. It requires about seven days for burning. Two kilns are in use, each of which has a capacity of 200,000 bricks. Wood is used for fuel. Daily output, 16,000 bricks. Size of bricks, 8¾ by 4¼ by 2½ inches.

FRANKLIN COUNTY.

GENERAL GEOLOGY.

In the extreme northern part of Franklin County, along Mulberry River and the tributaries entering that stream from the north, rocks are exposed that underlie the whole series of the coal-bearing rocks. These are the lowest and oldest rocks of Franklin County, and consist in part of beds of limestone. So far as is now known no clays or clay shales are associated with these old limestones. South of these exposures along Mulberry River the rocks of all the rest of the county are newer and are higher up in the geologic column and belong to the coal-bearing rocks or the series known as the "Coal Measures"—a series rich in clay shales and fire clays.

The rocks at and near the surface over most of the county are geologically somewhat higher than the coal beds found at the Ouita,

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Spadra, and Coal Hill mines. The Spadra shale, with the accompanying coal, extends westward from Allister about 7 miles into Franklin County. The Spadra shale covers all the area within T. 9 N., R. 26 W., lying south of the section line between secs. 13 and 24, and extends still farther south, to Arkansas River. They likewise include secs. 25 and 36, T. 9 N., R. 27 W. Over a large part of this area clay shales are associated with the coal, and much of this deposit promises to be available for the manufacture of fire-clay products and also for sewer pipe and paving brick.

Both north and south of the area here mentioned, as well as west of it, the rocks are higher in the geologic column. They consist, however, of shales and sandstones that closely resemble those lower down, in the coal-producing rocks.

The following characteristic section, exposed on the east bluff of Arkansas River by the railroad about a mile southeast of the town of Ozark, shows the kinds and thickness of most of the rocks of Franklin County:

Section near Ozark.

	Feet.
Sandstone	50
Shale	90
Sandstone	15
Shale	70
Sandstone	10
Shale	75
Sandstone	50

In the southern part of Franklin County there is a series of rocks that stands higher in the geologic column than those included in this Ozark section. These higher rocks belong to the group which has been called in Arkansas the "Poteau." They cover all of Franklin County south of Short Mountain Creek and south of the Vesta coal bank in T. 8 N., R. 29 W. These higher rocks are likewise exposed over a comparatively small area northeast of Ozark. They form what is called the Philpott coal basin, which extends from Moomaw's coal bank eastward (and a little northward) for about 16 miles. These uppermost formations include many beds of shale and also the coal beds of the upper productive part of the coal-bearing rocks and the fire clays associated with the coal beds.

CLAY DEPOSITS.

CLAY SHALES.

Unfortunately only one analysis has been made of a sample of clay from Franklin County, but it seems safe to infer that the analyses of the shales of White, Pulaski, Johnson, and Sebastian counties give a good idea of the character of the clays and clay shales of Franklin County.

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It seems probable that the fire clays and the clay shales of Franklin County that show rather high refractoriness are capable of being extensively utilized. The following three exposures along the railroad near Ozark were noted by Mr. Kennedy:

In the SE. ¼ SW. ¼ sec. 12, T. 10 N., R. 26 W., a bed of fire clay 4 feet thick underlies 2 inches of broken coal and overlies the black shales exposed in the water courses of this district. About 2 miles east of Ozark, in the NW. ¼ sec. 8, T. 9 N., R. 26 W., in a cut on the track of the St. Louis, Iron Mountain and Southern Railway, there is an outcrop of fire clay 20 inches thick lying immediately beneath 3 inches of coal. The section exposed is as follows:

Section in railroad cut 2 miles east of Ozark.

	Ft.	In.
Flaggy sandstones	4	
Coal		3
Fire clay	1	8
Arenaceous shales and thin sandstone at the base.		

Analysis of clay from railroad cut 2 miles east of Ozark.

[Brackett & Smith, analysts.]

Silica (SiO_2)	62.92
Alumina (Al_2O_3)	23.60
Ferric oxide (Fe_2O_3)	3.17
Lime (CaO)	.23
Magnesia (MgO)	.57
Potash (K_2O) / Soda (Na_2O) (by difference)	3.77
Loss on ignition (H_2O)	6.74
	100.00
Water at 110°–115° C.	2.65

On the same railroad at the end of an embankment in the NE. ¼ NE. ¼ sec. 7, T. 9 N., R. 26 W., a small stream cuts through a bed of blue and yellow shales 8 feet thick. These shales are readily disintegrated by atmospheric action and are almost free from sand. They are overlain by a bed of sandstone about 1 foot thick.

In the SE. ¼ SE. ¼ sec. 6, T. 9 N., R. 26 W., the following section is exposed on a small stream:

Section on stream in sec. 6, T. 9 N., R. 26 W.

	Ft.	In.
Thin-bedded gray sandstones	4	3
Light-grayish blue clay		2
Coal		6
Dark-blue clay		2
Soft black argillaceous shales	5	

The black shales of this section are very friable and easily ground into a paste.

About 3 miles east of Ozark, in the NE. ¼ SE. ¼ sec. 8, T. 9 N., R. 26 W., the railroad cutting has been carried through a bed of white

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siliceous clay from 4 to 6 feet deep and about 140 yards long. When dry, this clay is white, but becomes bluish when wet. At both ends of the bank the clay loses its whitish color and becomes various shades of red.

RESIDUAL CLAYS.

It has already been pointed out in the chapter on the general geology of the State that the rocks of the coal regions of Arkansas which underlie the surface in Franklin County consist chiefly of alternate beds of sandstone, shale, fire clay, and coal. When argillaceous shales are exposed for a long time to weathering, they disintegrate so completely that they form plastic clays available for the manufacture of pottery, sewer pipes, paving bricks, etc. All the plastic clays found among the hills of Franklin and adjoining counties, especially those found in the upland valleys, have been formed in this way. These rocks were originally deposited as horizontal beds of sediments; but in Franklin County they have been pressed into gentle folds and worn away by erosion until they must be regarded as only the badly mutilated remains of the original deposits. But in spite of this folding and erosion and in spite of the talus of loose fragments and earth that cover the outcrops the beds may be readily traced by means of the geologic structure.

Only a few localities at which potter's clays have been found and worked will be mentioned here, but these clays can be found in abundance in Franklin County if a demand for them should arise.

On the Ozark-Kingston road, running east and west along the south side of sec. 20, T. 10 N., R. 26 W., blue and red shales of Carboniferous age appear in a ditch entering from the creek near the schoolhouse to the lane that turns north along the middle of the same section. These shales appear to be about 6 feet thick. About 30 paces farther north along this lane, in a small artificial opening, they are seen to have disintegrated into a light-blue clay, 3 feet of which is exposed at this place.

A clay or disintegrating shale, which appears to be the continuation of the shales last mentioned, occurs in the N. ½ NE. ¼ NE. ¼ sec. 29, T. 10 N., R. 26 W., as well as in the NW. ¼ NE. ¼ sec. 29 and the NW. ¼ NE. ¼ sec. 28.

TRANSPORTED CLAYS.

At Webb City, in the NE. ¼ NE. ¼ sec. 11, T. 9 N., R. 27 W., a bed of pottery clay is exposed in a ditch along the Ozark-Caulksville road. This clay is almost white, is mottled with small streaks of red, and where exposed has a thickness of 2 feet. Being of Pleistocene age and forming a horizontal bed, it probably has a considerable areal extent. The bed is covered with the usual waterworn cherty gravel

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and overlies gravelly red clay, which rests unconformably on black Carboniferous shales. The section at this exposure is as follows:

Section at Webb City.

	Feet.
Watertown gravel	2
Pottery clay streaked with red	2
Gravelly red clay	2
Black shales at base.	

The upper gravel of this section is only 2 feet thick where the clay is exposed, but on the hillside south of this exposure it is probably from 15 to 20 feet thick.

BRICK CLAYS.

Enormous quantities of good brick clays lie in the second bottoms of Arkansas River south of Altus, extending eastward along the river as far as the mouth of Horsehead Creek. At some places, as on the road from Altus to Roseville, these brick clays are from 20 to 30 feet thick. The bricks made from these clays are gray in color and spotted with iron.

The area of brick earths around Ozark is limited to a small portion of the NW. ¼ sec. 36, NE. ¼ sec. 35, SW. ¼ sec. 25, and SW. ¼ sec. 26, T. 10 N., R. 27 W.

No bricks have been made at Ozark for several years. The last were made by W. A. Jennings in 1886.

About 1 mile north of the Roseville ferry, near the center of sec. 33, T. 9 N., R. 26 W., the Altus-Roseville road crosses a terrace of reddish, sandy, horizontally bedded clays similar to those of the terraces at Argenta and Fort Smith. At this locality the terrace is about 25 feet high. It may be traced for about 300 yards east of the road to a point where it is cut off by a small stream, and for about 100 yards west of the road. The clay is the same as that used for the manufacture of building bricks at Pendle & Morrison's yards in Fort Smith and at Argenta.

This terrace can no doubt be traced, at about the same elevation, from 50 to 75 feet above the river, for long distances on both sides of the river bottoms, though in many places it has been entirely removed by erosion.

At the church in the southwest corner of the SW. ¼ SE. ¼ sec. 28, T. 9 N., R. 26 W., a well about 30 feet deep shows a surface of yellow sandy clay or loam, while the materials brought up in cleaning show the bottom to be whitish gravels stained with iron.

Near the south line of the section in the SW. ¼ SE. ¼ sec. 21, T. 9 N., R. 26 W., a well 21 feet deep has the following section:

Section in well in sec. 21, T. 9 N., R. 26 W.

	Feet.
Yellow sandy clay or loam	3
Sticky yellow clay	18
Black shale at bottom.	

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Some small patches of brick earth occur close to Altus. These vary in extent from 1 to 10 acres. No bricks have been made here for several years.

The following is a section at Altus station, on the St. Louis, Iron Mountain and Southern Railway:

Section at Altus station.

	Feet.
Reddish-brown clay	3
Yellow clay	2
Whitish-yellow clay, visible	1

The colors seem to be the only distinguishing features, as each of the three divisions contains pebbles and their texture is otherwise alike.

In the N. ½ SE. ¼ sec. 16, T. 9 N., R. 26 W., the road passes a band of red sandy clay. It lies upon the slope of a hill, facing north. It is about 150 yards across, but its depth is not known.

At several places around Altus there are disintegrated blue argillaceous shales. On the Roseville and Altus road these shales are among red and blue shales and thin beds of sandstone close to George Page's house, in the SW. ¼ NE. ¼ sec. 2, T. 9 N., R. 26 W., and also in a ditch at a corresponding level in the NE. ¼ SE. ¼ sec. 16.

CLAY INDUSTRY.

In the NE. ¼ NE. ¼ sec. 20, T. 10 N., R. 26 W., J. M. Van Curom at one time manufactured coarse earthenware. The material used was a partially disintegrated red and light-blue argillaceous shale, from 18 inches to 4 feet in thickness, which occurs on the tops of the hills near by. The shale is overlain by a thin layer of gravel, and owing to the difficulty of separating the two the material used in this pottery contained a considerable quantity of small pebbles, which, with the appliances employed, the owner of the shop was not able to remove entirely. The red color of this material is so marked that even when ready for burning the ware has a light-red color.

Only the commonest classes of ware used in the neighborhood, such as churns, jugs, crocks, and jars, were manufactured. A small quantity of 6-inch piping was also made, for chimney flues.

The slip used for glazing was the ordinary black or Albany glaze. The kiln was not suitable for salt glazing. Owing to the general roughness of the ware a great amount of slip was used, leaving a rough surface streaked with slip in different stages of fusion. The construction of the kiln also allowed ashes to settle on the hot ware, where it became fixed by the glazing, thus adding to the roughness of the surface.

The fuel used in this kiln was mostly oak wood, but coal was also used.

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These shales make a coarse but strong ware, the loss by firing and drying being about 2 per cent. If they were properly crushed, ground, and screened, there is little doubt that good, strong sewer pipe might be manufactured from them.

GARLAND COUNTY.

About Hot Springs are many beds of argillaceous shales, which in places are decayed to soft, plastic clays. At the spring just below the old Hale bathhouse some of these shales are light colored and have decayed to a buff or dirty cream-colored clay, while the darker shales form on decay a very black, sticky mud.

Where the cut is made for the Government reservoir at the south side of the reservation, the rocks cut are black shales on the south and sandstones on the north. Both shales and sandstones are traversed by numerous quartz veins, and even where the shales have decayed and formed a soft, plastic clay broken quartz veins may be seen. These decomposed beds are injured for practical use by the presence of these small decayed quartz veins, which now remain as strings of angular quartz fragments.

These shales belong with the overlying rocks and are well above the novaculites, which end with the Garland conglomerate bed shown in the quarries on both sides of the avenue above the Hotel Arlington.

No clay industry of any kind is at present carried on in Garland County.

A peculiar form of kaolinite to which the name rectorite[a] has been given is found in Garland County in sec. 27, T. 2 N., R. 19 W. This material is tough and leathery, but it has the smooth, soapy feel so characteristic of the kaolins and of steatite. It occurs in association with the Ordovician sandstones of the region, but the deposits, so far as known, are only about a foot thick.

Analyses of rectorite from Garland County.

[R. N. Brackett, analyst.]

	1.	2.
Silica (SiO_2)	52.72	52.88
Alumina (Al_2O_3)	36.60	35.51
Iron (Fe_2O_3) (one determination)	.25	.25
Lime (CaO) (one determination)	.45	.45
Magnesia (MgO) (one determination)	.51	.51
Potash (K_2O) (one determination)	.26	.26
Soda (Na_2O) (one determination)	2.83	2.83
Loss on ignition	7.76	7.72
	101.38	100.41
Water at 110° C.	8.78	8.33

Rectorite as it comes from the ground ranges in color from pure white to reddish brown. The sheets are very flexible but entirely

[a] In honor of E. W. Rector, of Hot Springs, who originated the Geological Survey of Arkansas.

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without elasticity. It is infusible before the blowpipe, but when heated in the flame of a Bunsen burner it loses water and becomes brittle. Specimens of this kaolinite were sent to ceramic works to be tested practically, and the following report was made on the results by Homer Laughlin, of East Liverpool, Ohio:

The sample of what you call kaolinite sent me was duly received and carefully examined and tested under fire. The mineral is neither kaolin nor kaolinite, but just what it should be called I am unable to say, never in all my experience having seen any mineral of its kind. Unlike kaolin, it will not dissolve in water. It burns a white color and becomes very vitreous and strong. It can not be finished with a smooth face or skin, but roughs up like a blotting pad. It is certainly a very interesting and curious mineral, but I can think of no use for it in ceramic manufacture unless it could, after careful experiments, be made into novel ornaments.

Samples were also sent to Oliphant & Co., of the Delaware Pottery, at Trenton, N. J., but they were unable to say anything of its quality or market value.

Although rectorite is not now known to have any practical commercial value, it is mentioned here as of scientific interest and of possible future importance.[a]

GRANT COUNTY.[b]

Grant County is almost entirely within the area of the "Lignitic" (Tertiary). The surface is such as is characteristically found in the Tertiary area of this State, being a rolling surface, broken in the vicinity of the larger streams. The soils are sandy and thin on the uplands, while the higher ridges exhibit abundant novaculite gravels, at many places rudely stratified and everywhere small.

The divides are in many places wide and flat, or filled with a series of broad depressions which constitute sandy "slashes." All support a heavy growth of large and fine pine. The bottom lands are characteristically wet and clayey. They support an abundant growth of large white oak, red oak, and gum, with scattered groves of holly.

The general stratigraphy here given is the result of composite sections made up from well records and from sections in gullies and cuts made by streams. Near the mouths of the deeper ravines a sandy clay lies at the base of the hills.

The members of the Eocene (Tertiary) form a considerable portion of the surface of this county. As is well known, these members are largely arenaceous, with an admixture of thin clays of varying colors. Commonly these clays are erratically distributed in the form of small lenticular pockets. The pockets are disposed without observable vertical order, but appear to be most common near the top of the series. Their color is nearly everywhere drab to white, but at

[a] A mineralogical description of rectorite was published by R. N. Brackett and J. F. Williams in Am. Jour. Sci., 3d ser., vol. 42, 1891, pp. 16–21.

[b] The notes on Grant County were taken chiefly by R. E. Call and C. E. Siebenthal.

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some places, especially where heavy beds of sand are superimposed upon them, it is some shade of red.

In the NW. ¼ SE. ¼ sec. 35, T. 4 S., R. 15 W., near the mouth of a small tributary of Saline River, there is a bed of light-drab and fine-grained fire clay, underlying a 2-foot bed of lignite. The clay is exposed for about 2½ feet, but its total thickness is not known. The locality is difficult of access and at present without transportation facilities.

The lignite found at this locality has been tried in blacksmiths' forges at Sheridan with indifferent success. Several sacks of it were taken to that village and burned in grates; it is reported to have burned well. On exposure it falls to pieces, eventually becoming a coarse powder, which circumstance would prevent its general use for fuel were it otherwise suitable.

A tough, plastic, gray clay outcrops on E. G. Davis's place, in the SW. ¼ NW. ¼ sec. 25, T. 6 S., R. 15 W. A well 300 yards west and about 25 feet higher went through 25 feet of sand. The well at the gin in Sandy Springs, which is about 400 yards south of the first well, showed from 8 to 10 feet of white sand. The road for 1½ miles southwest of Sandy Springs shows red sand but no gravel. At one place the sand much resembles chocolate clay.

About 20 feet of a dark sandy clay outcrops in a stream bank in the SW. ¼ NW. ¼ sec. 31, T. 6 S., R. 14 W.

Stephen Heard's well, near the northwest corner of the SW. ¼ sec. 31, T. 6 S., R. 15 W., shows the following section:

Section of Stephen Heard's well.

	Feet.
Red clay	15
Potter's clay	7
Red clay	8
White gravel (some bowlders as large as a man's head)	5
Clays of different colors, the lowermost containing leaf impressions.	31
White sand	3
	69

Plastic clay is reported near the southwest corner of sec. 18, T. 6 S., R. 15 W.; also on the Davis farm, near the center of sec. 10, in same township. A very white plastic clay is reported to occur in same township near the schoolhouse in sec. 9, about the middle of the west side, on a small drain flowing into Brushy Creek.

Plastic gray clay outcrops in the NW. ¼ NW. ¼ sec. 31, same township, in a drain flowing south in Gum Bottom. Similar clay which has been used for pottery outcrops in drains and is exposed on the breaks of the hills farther east all along the north side of Gum Bottom.

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Section of well at Sheridan.

	Feet.
Light sandy soil with abundant novaculite pebbles; occasionally clayey	3
Small, waterworn novaculite gravels, with much purplish quartzite: rudely cross-bedded and stratified	13
White sand, with lenticular pockets of drab, red, or yellow clay; pebbles rare toward the top	43
Blue to black horizontally stratified clay, containing in its partings abundant lignite particles and mica scales. Well sections commonly end in this member, which has at no point been penetrated, at 8 to 10 feet below the top.	

In the roads from Benton to Sheridan and from Sheridan to Pine Bluff, near the top of every hill which is crossed, there are thin layers of a red or yellow ocherous clay which has nowhere been found in heavy beds. The same clays are found on the faces of the higher bluffs near all the streams and form a conspicuous feature of all the deeper washes.

Limonitic or buckshot brick clays similar to those used at Malvern occur in the bottoms of all the streams, especially in those of Lost, Hurricane, and Darysaw creeks, and in that of Saline River. The distribution of these limonitic clays is well defined. They skirt the bases of all the hills and extend over the bottoms of all the creeks and deep branches, forming the roadbed in all such localities. The cold and wet character of the bottom lands is due to their presence, for water does not readily percolate through them. Throughout the bottom lands they rise here and there to the surface in barren patches. A map of the region including the river and creek bottoms would be a map showing the distribution of the limonitic hardpan or buckshot clays.

The pine flats or pine slashes of the higher lands are of a sandy, drab-colored clay, which is used locally for building chimneys. In one place, at Sheridan, it has been employed in the manufacture of rough bricks. The clay is not well suited to this use, containing too much sand, too little iron, and burning to a poor color. The jail at Sheridan is built of bricks made from this clay—the only kiln of brick known to have been made in the county.

The region along Saline River, especially at the base of the bluffs, gives most promise of exhibiting deposits of fire and pottery clays, this region being the one that best exposes the deeper lying Tertiary clays.

At numerous localities throughout Grant County, and notably in the SW. ¼ SW. ¼ sec. 11, T. 5 S., R. 13 W., there is a highly ferruginous sandstone at places attaining a thickness of 1 foot. This rock occurs commonly well up on the sides of the hills and not infrequently caps their summits. In other localities the gravels are conglomerated,

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or cemented, with iron oxides, and may be removed in large masses from the hills. Both sorts are locally used for underpinning houses and barns, and occasionally for building chimneys. In a region where other hard rock is entirely wanting, these beds appear to be very valuable for both these uses.

The water from the wells has a bitter saline taste, due possibly to epsom salts (magnesium sulphate) or to sulphate of iron. Only water coming from the numerous springs along the contact line between the gravels and the underlying clays or clayey sands appears to be free from this bitter taste.

It is believed that the beds underlying the surface members are equivalent to those at Camden.

No plant of any kind in the county is engaged in the manufacture of brick or other clay products.

GREENE COUNTY.

GENERAL GEOLOGY.

Greene County is divided into three natural topographic provinces—the St. Francis River sunken lands on the east, Crowleys Ridge in the center, and the Cache River bottoms on the west.

The St. Louis, Iron Mountain and Southern Railway from Jonesboro to Piggot runs along the second bottom land on the east side of Crowleys Ridge. The second bottom land is formed of reworked material derived from Crowleys Ridge. It is a yellow-clay soil, well adapted to the cultivation of wheat and corn. At Paragould the yellow-clay land extends about 2 miles eastward from the foot of the ridge.

East of the yellow-clay second bottom land comes a narrow band of glady clay soil which extends eastward for about 2 miles. The clay that forms this strip is a white to gray joint clay or pipe clay, which is very tough when wet but pulverizes completely when turned by the plow and exposed to the sun and rain. In texture the soil is very similar to that of the second bottom to the west.

The western edge of the white glady land marks the western limit of high water of St. Francis River. Until recent years backwater from the river would stand on the land until the iron oxide had been leached out so as to leave the soil cold and lifeless. Where the land has been drained and the water kept from standing on it, the soil within three to four years assumes a brown to yellowish color and becomes more productive.

The soil of the country east of the glade land is composed of fine silt and sand. The sandy land stands 8 to 10 feet lower than the white glady land to the west.

The Tertiary rarely appears at the surface along the eastern edge of Crowleys Ridge in Greene County, but is covered by later deposits,

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consisting of Lafayette gravel and sand and loess. In one of the wells at Paragould the Tertiary was encountered below 20 feet of yellow clay and about the same thickness of iron-stained gravel (Lafayette).

On the western edge of the ridge the Tertiary sands, interstratified with variegated clays, occur at various places along the steep and in places almost vertical cliffs.

The hard quartzose sandstone ledges which are found at the foot and on the sides of the ridge near the railroad, in the northwestern part of Craighead County, outcrop in no less than five localities in Greene County. One occurs on the line between Greene and Craighead counties, one near Walcott, one near Crowley, one west and another northwest of Gainesville, and still another is reported 3 miles west of Paragould. At each place the sandstone is similar in appearance to the Tallahatta of central Mississippi, but its exact age is as yet unknown.

Buckshot clay lands and the sandy bottom land of Cache River bottom occupy the country to the west of Crowleys Ridge.

CLAY INDUSTRY.

The only clay used in the county for other than agricultural purposes is the loess and reworked loess used in the manufacture of bricks at Paragould and Gainesville. A sample was taken from the loess at the village of Gainesville, where it is employed in the manufacture of bricks. It is hardly a typical loess, but it is closely allied to it.

Analysis of loess used for brickmaking at Gainesville.

[Dried at 110°–115° C. Brackett & Smith, analysts.]

Silica (SiO_2)	81.34
Alumina (Al_2O_3)	9.71
Ferric oxide (Fe_2O_3)	3.67
Lime (CaO)	.29
Magnesia (MgO)	.33
Manganese (MnO)	Trace.
Alkalies, by difference	1.55
Loss on ignition	3.11
	100.00
Air-dried sand in air-dried specimen	35.00

The deposits from which this sample came lie on the slope of a hill, the base of which is composed entirely of Tertiary partly colored sands. Except for the small percentage of sand in the air-dried specimen and the greater oxidation of the iron this soil does not differ materially from typical loess.

The bricks from the plant of the Paragould Brick Company are made from the reworked loess. Dry-pressed and wet-mud bricks are

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made. The clay for the wet-mud bricks is tempered and molded by steam, dried in covered racks, and burned in updraft clamp kilns. It requires about seven days for drying and fourteen days for burning. Wood is used for fuel.

Two kinds of clay are present in the pit. The upper, porous yellow stratum is best adapted for making brick. The lower stratum is a compact, plastic gray clay which can not be used for brick without being mixed with the overlying yellow clay. When used alone it checks badly in drying. The wet-mud machine has a capacity of 20,000 bricks a day.

The clay for the dry press is stored in a dry shed for several weeks and is then molded into bricks and set in an updraft kiln. It requires about seventeen days to burn the dry-press bricks. The machine has a capacity of 15,000 bricks a day. About 50 per cent of the bricks made at Paragould are sold at the kiln; the remainder are shipped to neighboring towns.

The following analysis was made from the reworked product of the loess at Paragould:

Analysis of brick earth from the surface at Paragould.

[Dried at 110°-115° C. Brackett & Smith, analysts.]

Silica (SiO_2)	79.07
Alumina (Al_2O_3)	8.79
Iron (Fe_2O_3)	2.54
Lime (CaO), Magnesia (MgO), Alkalies (by difference)	2.37
Manganese (MnO)	3.68
Loss on ignition	3.55
	100.00
Air-dried sand in air-dried clay	43.64

The percentage of iron found in analyses of Greene County clays is commonly sufficient to give the bricks a deep shade of red. In analyses of clay from Paragould only a trace of manganese appears. The red color of bricks made from loess clays, therefore, seems to be due to the iron alone. To get brown colors it will be necessary to add manganese-bearing clay. Lime and other alkalies form an inconsiderable portion of the whole clay. From these loess soils the best quality of pressed brick may be made. This has already been practically demonstrated at many places along the upper Mississippi River.

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HEMPSTEAD COUNTY.

GENERAL GEOLOGY.

In its general features the geology of Hempstead County is very simple. The rocks of the northern part of the county are upper Cretaceous, while those of its southern part are Tertiary. The upper Cretaceous rocks are covered with great beds of waterworn material—cobblestones, pebbles, and sand. This gravel is especially abundant about Bingen and between Nashville and Hickory Creek.

The line of juncture between the Cretaceous and the "Lignitic" (Tertiary) where the latter overlaps the former enters the county at a point northeast of Hope, south of the railroad, and, following a generally southwest direction, crosses Bois d'Arc Creek about 4 miles southeast of Fulton. South of this line everything in the county is Tertiary, except, of course, the alluvial flood plains of the streams and the occasional patches of Pleistocene materials. The Cretaceous, however, dips to the southeast beneath the Tertiary, and deep wells sunk in any part of the Tertiary region must sooner or later strike the Cretaceous rocks. As elsewhere in the State, the Tertiary beds are mostly soft and are disposed in horizontal or nearly horizontal strata. The whole of this Tertiary part of the county has been more or less denuded, but in some places the streams have cut out the beds to make the valleys, leaving the remnants of these beds in the hilltops, where they are covered with a thin coating of sand, gravel, and loam.

CLAY DEPOSITS.

In southern Hempstead County, as elsewhere in the Tertiary regions, pottery clays are found in patches. This fragmentary nature of the pottery clay deposits may be due either to the original pockety nature of the sediments or to subsequent erosion, which has removed a great part of the original clay beds. In prospecting to determine the extent of known deposits these points should be determined first and prospecting carried on accordingly.

The pottery clay deposits of Hempstead County, so far as they have been practically tested, are best known in the neighborhood of Spring Hill, a town about 6 miles south of Hope, and in T. 13 S., R. 24 W., 4 miles south of Hope.

CLAY INDUSTRY.

Foley pottery.—There was formerly a small pottery 4 miles south of Hope, operated by John Foley. The clay was obtained from a bank opened in the NW. ¼ SE. ¼ sec. 18, T. 13 S., R. 24 W. The clay deposit is about 150 yards in diameter, as shown by test pits, and aggregates 14 feet in thickness. It is divided into two beds, an

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upper one, 4 feet thick, of a clay that is of bluish color when wet, but nearly white when dry. This bed contains seams of indurated or slaty clay, so hard as to require grinding. The lower bed of clay is 10 feet thick, and when wet is of a pinkish hue. It contains some iron stains and weathers to a yellowish color.

The upper one of these clay beds was used for the manufacture of flower pots and the various classes of pottery demanded in the district. The lower bed was used exclusively for making fire bricks. Bricks made from this clay are light and porous, and are of a cream color. To render the clay porous enough for brick manufacturing sawdust was mixed with it before molding.

Analyses of the clays used by Mr. Foley in the manufacture of pottery and fire bricks are given below. Each specimen analyzed was dried at 110°–115° C.

Analyses of clays from beds near Hope.

[Brackett & Smith, analysts.]

	1.	2.	3.
Silica (SiO_2)	76.33	73.87	72.48
Alumina (Al_2O_3)	16.04	17.38	18.24
Ferric oxide (Fe_2O_3)	1.24	1.64	1.52
Lime (CaO)	.99	1.46	1.98
Magnesia (MgO)			
Potash (K_2O)			
Soda (Na_2O)			
Loss on ignition (H_2O)	5.40	5.65	5.78
	100.00	100.00	100.00
Sand	13.00	.....	3.62
Water at 110°–115° C.	2.23	1.92	1.69

Other clays suitable for the manufacture of fire brick may be found within a short distance of the Foley pit.

Spring Hill pottery.—Before the civil war a small pottery was operated at Spring Hill, where several beds of clay are available for pottery.

At present (1906) a pottery is operated near Spring Hill by Michael Foley. Tertiary clays, such as those used at Texarkana and Benton, are used for the manufacture of jug ware, crocks, and churns.

Hope brick works.—A large brick plant was established at Hope in 1904 by Messrs. R. E. and N. P. O'Neal. Common building bricks are made. The bricks are molded by steam in a Hercules Senior machine, dried by the pallet and rack system, and burned in updraft clamp kilns. The length of time required for drying depends on the weather. About ten days are necessary for burning. The fuel used is wood. Three kilns are used. The bricks are made from the surface clay. The plant has an output of 32,000 bricks a day.

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HOT SPRING COUNTY.

GENERAL GEOLOGY.

The Tertiary border enters Hot Spring County from the northeast, in Saline Township, and crossing the Hot Spring Railroad a mile south of Butterfield and Ouachita River at Rockport, passes into Clark County a few miles above the mouth of Bayou de Roche. To the south and east of this line lie the nearly horizontal Tertiary beds, while to the north and west the county is mountainous and the Paleozoic rocks are much folded, broken, and eroded. Though it is not impossible that pottery clays may be found among the disintegrated shales of the hilly regions, the Tertiary is eminently the region of pottery clays, not only in Hot Spring County, but in the whole State of Arkansas.

The Tertiary formations have been denuded in Hot Spring County, as elsewhere, so that the uppermost beds, being deeply scored by gullies, ravines, and valleys, are more or less fragmentary. Where the pottery clay beds belong with this uppermost group they have been exposed in the sides of the hills, but their margins have been covered and concealed by the less soluble and less portable remains of the overlying beds and by waterworn materials of Pleistocene age. The structure of the region is thus obscured in spite of its great simplicity, and for this reason the pottery clays have been found only where they happen to be uncovered by some natural process, as in the channel of a stream, or artificially along roadsides or in wells.

CLAY DEPOSITS.

PERLA SWITCH CLAYS.

The only place at which the Tertiary pottery clays are known to have been worked in Hot Spring County is at Perla switch, about 2 miles east of Malvern station on the St. Louis, Iron Mountain and Southern Railway. At this place Messrs. O. C. Atchison & Co. manufacture the ordinary kinds of common pottery ware, such as churns, jars, crocks, jugs, fruit jars, sewer pipes, flue linings, and fire bricks. The clay is obtained from a bank on the west side of a small stream in the NE. ¼ SE. ¼ sec. 24, T. 4 S., R. 17 W.

The section on page 113 shows the relation of the pottery clays of Atchison's pit to the hill on the west and south.

The clays are covered by 3 to 5 feet of gravelly, sandy soil, the pebbles of which are principally of quartz and novaculite.

The upper part of the clay bed has occasional pockets of pebbles, formed in cavities made by the decay of roots and stumps, the upper gravel having fallen into these openings.

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The light lead-colored clays forming the upper part of the clay bed merge into mottled clays below, and these in turn are followed by snuff-colored layers, while the lowest part of the bed visible is a dark-brown mucky looking clay. Fossil leaves occur only in the two lower members. If they ever existed in the upper part of the clay they have been destroyed by the action of percolating water.

The depth of this clay bed was tested with an earth auger and was found to be 30 feet. The bed is more sandy below, however, and contains some iron pyrites, which injures it for pottery making.

The light-colored upper part (10 feet) of Atchison's clay pit is used chiefly for the manufacture of pottery. This clay burns to a hard, solid body and is easily glazed with either the Seneca Falls or Albany slip clay or with salt. The lower bed, which consists of dark clay, is utilized for the manufacture of fire bricks, sawdust

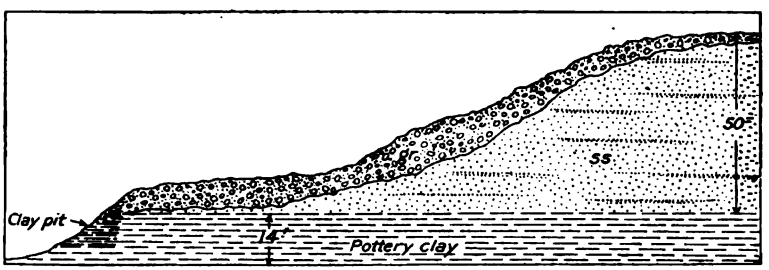

FIG. 11.—Section at Atchison's clay pit at Perla switch, Hot Spring County. *ss*, Sandstone; *gr*, gravel.

being mixed with the clay to give the bricks the necessary texture and porosity. This clay burns to a light-cream color and the ware has a remarkable bell-like, metallic ring.

Analyses of clays from Perla switch.

[Brackett & Smith, analysts.]

	Light-colored pottery clay.	Dark-colored brick clay.
Silica (SiO_2)	73.24	72.59
Alumina (Al_2O_3)	19.61	16.08
Iron (ferric) oxide (Fe_2O_3)	1.04	1.18
Lime (CaO), Magnesia (MgO), Potash (K_2O), Soda (Na_2O) (by difference)	.78	3.81
Water (H_2O)	5.33	6.34
	100.00	100.00
Water at 110°-115° C.	2.01	2.08
Fine white sand	5.40	.....

On John Wilkerson's land in the N. ½ NE. ¼ sec. 35, T. 4 S., R. 17 W., there is a deposit of light-colored pottery clay from which the

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Atchison Company formerly obtained its supply. This clay has been recently tested for fire bricks by the Clark Pressed Brick Company, of Malvern. It is thought that it will prove of excellent quality for this purpose.

OTHER CLAYS.

The topography of the country about Perla switch and the disposition of the Tertiary beds lead to the belief that the pottery clays found at the Perla pits may also be found on the northwest side of the railroad. Similar beds may reasonably be looked for on both sides of the railroad at Traskwood, and along the line of hills northwest of the road. These clays, however, may vary locally somewhat, both in character and in thickness, here disappearing altogether and there forming thick pockets, but are probably rather constant in geologic position.

The gravel and sand covered ridge south of Malvern is of the same geologic structure as that at Perla switch, and similar pottery clays might reasonably be expected almost anywhere in that region.

West of the ridge on which Malvern stands a dark clay containing more or less lignite is found in wells. The following is the record of a well in sec. 22, T. 4 S., R. 17 W.

Section in well west of Malvern.

	Feet.
Gravel	12
White clayey gravel	2
Black lignitic clay	13
	27

The black clay was not completely penetrated in this well, and its thickness is not known. The bed may be the equivalent of the beds worked at Perla switch. The same bed has been found in other wells in section 22.

A sample of this clay was burned with the following results:

Test of clay from sec. 22, T. 4 S., R. 17 W., showing loss on ignition.

	Feet.
Water and volatile matter	17.44
Fixed carbon	5.61
Total loss	23.05

A large bed of light-colored or white clay underlies the gravel bed in the rear of Orr's Commercial Hotel at Malvern and extends southward along the hills for several hundred feet and northward nearly across the street next east of the hotel. It varies from 6 to 8 feet in thickness, and is almost pearly white, streaked with yellow or brown—the color being produced by infiltration of iron-charged waters along cleavage joints. It is not known whether the bed has been reached in wells farther east.

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The well dug for the planing mill at Rockport is said to have passed through a bed of potter's clay before reaching the fossiliferous limestone, but this clay has not been examined.

The following is the section of A. Parrish's well, near the center of the NE. ¼ sec. 7, T. 6 S., R. 17 W., as reported by Mr. Siebenthal:

Section in well of A. Parrish.

	Feet.
Red clay	1
White clay	8
Darker clay	2
Lignite	1
White clay	2

In the NE. ¼ sec. 5, T. 6 S., R. 17 W., according to Mr. Siebenthal, the Clarkson-Christopher Lumber Company's tramway cuts 20 feet of slaty-blue plastic clay which weathers very much like the olive-green clays of Little Rock. This clay contains leaf impressions. The locality is 460 feet above tide.

The following is the section record of Ford's well in the SE. ¼ sec. 33, T. 5 S., R. 17 W.:

Section of Ford's well.

	Feet.
Soil and gravel	24
Tough bluish clay	2
Sand in bottom.	

White plastic clay is reported on a small stream in the SE. ¼ sec. 3, T. 5 S., R. 17 W. Mr. Siebenthal is of the opinion that it is good potter's clay.

The following is a record of the well section at Kramer's, in sec. 19, T. 6 S., R. 17 W. This place is 430 feet above sea level (barometer):

Section of well at Kramer's.

	Feet.
Soil and gravel	10
Blue clay	15
Lignite	2
Blue clay	11
Lignite	2
Hard gray clay	2
Lignite in bottom.	

In the NE. ¼ sec. 35, T. 6 S., R. 18 W., about a quarter of a mile above Sulphur Springs, Mr. Siebenthal reports 4 feet of dark-gray clay exposed in the bank and bed of the creek. The weathered upper part of this bed is dark and is said to resemble the clay in the Perla switch beds above Malvern. It is said that some of this clay has been successfully used for manufacturing pottery. A practical test of it was made by the Rev. Mr. Clark, who burned it on the west side of the Ouachita, below Rockport.

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In addition to the localities mentioned above, it is highly probable that fine pottery clays are widely distributed throughout all of that part of Hot Spring County lying south and east of the St. Louis, Iron Mountain and Southern Railway.

MAGNET COVE KAOLIN.[a]

The rocks of the Magnet Cove are largely feldspathic, and in places they are decomposed to great depths. The only kaolin found in Magnet Cove, however, occurs in a few small scattered bands and patches, while the residuary clays as a whole are full of grit, iron oxide, and incompletely decayed fragments of mica. These clays are not available for brickmaking, and even the earth used for lining chimneys is hauled from the region of sedimentary rocks outside of the cove.

A well 49 feet deep, dug at the residence of J. F. Moore, in the SW. ¼ NE. ¼ sec. 19, T. 3 S., R. 17 W., is all in eruptive rock, decayed in place, much of which is soft enough to be removed with the spade. Only very thin streaks of kaolin were found in this decayed rock.

A small deposit of kaolin is uncovered east of I. N. Johnson's house, in the southeast corner of the cove, NW. ¼ NE. ¼ sec. 29, T. 3 S., R. 17 W., and a few layers are exposed in the Hot Springs road at the west end of the cove near Thomas Holt's house, and also in his well, NE. ¼ NE. ¼ sec. 24, T. 3 S., R. 18 W.

At John Neusch's house, NW. ¼ NE. ¼ sec. 30, T. 3 S., R. 17 W., small streaks of kaolin, perhaps 2 inches wide, were found in digging a well. The earth taken from Mr. Neusch's well was examined shortly after the well was dug. The little lumps of kaolin in it are of excellent quality, but there is nothing to lead one to expect to find it in workable quantities. Afterward lumps of this kind of kaolin were sent to the office of the State survey for examination, with the report that there was an inexhaustible quantity of it, but following up this rumor it was found that the sample came from Mr. Neusch's well. None of these small deposits have any economic value. It is possible, however, that kaolin may yet be found in Magnet Cove in quantities and of a character that will render it valuable. This possibility is suggested by the nature of the rocks and by their profound decomposition.

Bringier speaks of china clay in the "Wichita" cove,[b] and Doctor Owen mentions beds of kaolin from 3 to 15 feet in thickness.[c] These reports have not been confirmed. The places referred to by Owen were "in wells dug by George Piles and Mr. Plank;" if the locations can be found it may be well worth while to verify the matter.

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[a] The geology of the Magnet Cove region is discussed in detail by Dr. J. Francis Williams in Ann. Rept. Survey Arkansas for 1890, vol. 2.

[b] Bringier, L., Am. Jour. Sci., 1st ser., vol. 3, 1821, p. 26.

[c] Owen, D. D., Second report of a geological reconnaissance of the middle and southern counties of Arkansas in 1859 and 1860, p. 162.

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CLAY INDUSTRY.

Clark Pressed Brick Company, Malvern.—The plant of the Clark Pressed Brick Company is located near the main track of the St. Louis, Iron Mountain and Southern Railway, on the south side of the town of Malvern. The bricks when burned are loaded directly from the kilns into cars.

The clay used for making the brick is obtained from the second-bottom hummock of Ouachita River, about three-fourths of a mile from the kilns. A steam shovel is used in the pit for digging the clay, which is loaded into small cars. The cars are drawn to the kiln on a steel-railed tramroad by means of a small locomotive.

Through the summer and fall the common stiff-mud bricks are made, and dry-pressed brick during the winter. The clay is high in silica, burns to a deep Indian red color, and makes a durable, tough brick.

The bricks are made in an end-cut machine and dried in an artificial drier. The green bricks are then placed in large 250,000 up-draft kilns. It requires seven days for burning a kiln, using 110 tons of coal.

The plant has a capacity of 75,000 bricks a day. Forty-eight men are employed; two men in the pit, one man to run locomotive, six men in setting dried bricks in the kilns, and the remainder in feeding pug mill, carting green bricks away to drier and, when dried, to the kilns, running machinery, loading burned bricks, and firing kilns.

Malvern brick and tile works.—This plant manufactures white front, paving, and fire bricks. The white plastic clay, which is doubtless of lower Tertiary age, is used. The bricks are made in a stiff-mud machine and dried with artificial heat. The bricks are burned in round down-draft kilns.

JACKSON COUNTY.

The greater part of Jackson County lies east of White River and its principal tributary, Black River. These two rivers in this county practically mark the eastern border of the old Paleozoic rocks. The greater portion of the county is therefore in lowlands of Quaternary age. Two townships that lie directly south of Independence County are mostly in the Paleozoic area. A narrow ridge west of Depart Creek in T. 10 N., R. 4 W., contains limestone and marl bearing a fauna that belongs to the midway stage of the Tertiary. The Tertiary is recognized in but one place north of this, namely at Newark, where a bed of greensand marls has been found containing shark's teeth and some unrecognizable invertebrate fossils.

The surface of the lowland is similar to that of most of the counties in the Quaternary of this section of the State. Near the streams

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there are large sand ridges of alluvial origin with a subsoil of yellow to buckshotty clay. In places these alluvial deposits extend 4 to 6 miles back from the stream. Abandoned streams can likewise be traced by old channels, with alluvial deposits extending for a greater or less distance on both sides. Some of these old channels now form lakes.

It appears that the surface of the country was originally very nearly level, with but slight depressions, sufficient to determine the location of the drainage streams. Repeated overflows carried large quantities of alluvium, which was deposited as sand ridges near the streams. The ridges farthest removed from the streams or abandoned channels are all higher than the prairie lands. The soil of the prairie lands is generally a yellowish to gray clay, in places containing more or less fine sand. The difference between the two soils is likewise marked by differences in species of virgin timber and differences in the character of crops produced. The alluvial soil is generally much more fertile than the prairie soil.

No clay products of any kind are manufactured in Jackson County. Brick clays are available at Grand Glaise, in the southwestern part of the county. The loam that forms the prairie lands back from the streams, especially in the central part of the county, could be made into common building brick. A clay subsoil that outcrops in the bank of White River at Newport is suitable for making a good building brick.

JEFFERSON COUNTY.

CLAY DEPOSITS.

The greater part of Jefferson County is covered by alluvial deposits of Arkansas River and of Bayou Bartholomew. Running along the western edge of the county, however, is a strip of the Claiborne (?) formation (Eocene), having a width of 10 or 12 miles. In the river bottoms brick clays occur here and there and in some of the slashes there are occasional patches of clay available for the manufacture of cheap grades of pottery, but the best clays of the county are in the western tier of townships. At a place called White Bluff these Tertiary beds are well exposed on Arkansas River. The accompanying section recorded at that place shows the relations of the clays to other beds.

Section at White Bluff, on Arkansas River.

	Feet.
1. Soil and sand	8
2. Light-gray sandy clay	9
3. Light-pink clay with fossil leaves	8
4. Laminated dark shaly clay	9

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	Feet.
5. Dark lignitic clay with two bands of lignite	5–9
6. White sand	4–8
7. Laminated dark shaly clay	11
8. Dark-bluish sandy marl	22

Of the clays exposed in this section No. 3 is probably the most promising. They are well worth testing in any case. The nearness of these beds to water transportation on Arkansas River gives them additional importance.

These beds may continue across the country and at other places may be found under a thinner covering than that overlying them at this place.

CLAY INDUSTRY.

Pine Bluff.—Six yards were formerly engaged in the manufacture of soft-mud bricks at Pine Bluff. The bricks were all made by hand and dried in open yards. In many instances the bricks were insufficiently dried and burned, and as a result a very common and inferior product was made. These yards have all sold out, quit business, or consolidated, and at present there are but two plants doing business in the city.

Pine Bluff Brick Company.—This plant was incorporated in 1892. Common soft-mud bricks are made. The bricks are molded by steam in a Hercules Senior machine, and dried artifically thirty-six hours in a Standard drier. Six to seven days are necessary for burning after they are thoroughly dried. They are burned in up-draft kilns, which have a capacity of 375,000 to 400,000 bricks. Wood is used for burning, about three-fourths of a cord per thousand bricks being used. The capacity of the plant is 40,000 bricks a day. The bricks are made from a sandy surface clay. Size of green bricks 2½ by 4½ by 9 inches; shrinkage, none.

Conley brick plant.—A small brick plant is operated by J. H. Conley at Redfield, in the northwestern part of the county. The plant was established in 1898. The bricks are made from the common yellow surface clay. They are dried in the sun and burned in an up-draft kiln of 50,000 capacity. The bricks are sufficiently dried in two days to place in the kiln, and are burned in about seven days. Hard wood is used as fuel, about one-half cord being used for burning a thousand bricks. When thoroughly burned the shrinkage in a kiln 10 feet high is about 6 inches. The daily capacity of the machine is 5,000 bricks.

O'Neal & Rogers plant.—A plant has recently been established at Pine Bluff by Messrs. O'Neal & Rogers, but no particulars concerning it were obtained.

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JOHNSON COUNTY.

GENERAL GEOLOGY.

The geology of Johnson County is similar in its broader features to that of Pope County to the east, of Franklin on the west, and of Logan on the south. The rocks are of the same geologic age, but there are not the same strong contrasts between the different formations that characterize either Pope or Logan counties. The rocks are chiefly sandstones, shales, and coals. The lowest rocks in the county are exposed in the bottoms of the narrow valleys of the northern part of the county, on the headwaters of Mulberry River and of Little Piney Creek, and about Fort Douglas on Big Piney Creek. The rocks of the lofty mountains about Melson, Ozone, and Mount Levi, although they are much higher than those of the valleys about them, are nevertheless geologically lower than the coal-bearing beds of the Arkansas Valley about Clarksville and Coal Hill.

CLAY DEPOSITS.

CLAY SHALES.

The clays and clay shales of Johnson County that are likely to have economic value lie along the line of the Little Rock and Fort Smith Railway and along or near Arkansas River. The shales of other parts of the county are just as good intrinsically as those near transportation, but owing to the expense of getting them into market they are necessarily of less importance. For this reason but little is said here in regard to the clays and clay shales of the more remote parts of the county.

The Hartshorne sandstone bed, which forms Ouita Ridge, in Pope County, continues westward into Johnson County, forming the broad ridge east and north of Piney station. Those same sandstones continue northward through the eastern section of R. 22 W. South of Arkansas River this sandstone forms the great ridge 2 miles due south of Piney station. The Spadra shale, containing the Ouita coal bed, forms a narrow trough south of Piney station. This trough widens abruptly toward the west and north, so that the Spadra shale underlies all the country west of Piney and west and north of Knoxville for 8 miles or more. These same shales are exposed in the lower portions of the hills east and south of Clarksville, along the valley of Spadra Creek, west of the mouth of that stream to Spadra and Montana, about the base of Spadra Hill, at Hartman, and along the base of the hill just north of Hartman. Throughout this entire area of the Spadra shale clay shales available for the manufacture of paving bricks, sewer pipe, and fire-clay goods may be found, and at many places they are conveniently exposed.

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These shales are at some places hard and at others are soft and plastic. Where they have not been exposed long or favorably they are liable to be hard. In places they are disintegrated to a depth varying from 1 foot to 10 feet. Where these shales are soft and plastic they may be used without grinding for the manufacture of fire bricks, stove linings, paving bricks, and sewer pipes. If the shale is not soft and plastic it can be used only after being ground.

The clays and clay shales usually accompanying the coal beds are liable to prove valuable as fire clays.

The clay underlying the coal at the Stiewell mine No. 2 at Coal Hill is hard and shaly when freshly mined but readily breaks up under the influence of the weather. When burned this clay becomes white. Its thickness is uncertain, but it is said to range from 12 to 18 inches.

At the Allister slope at Coal Hill the flooring is said to be a hard black shale, but no definite information could be obtained regarding its thickness. The waste material brought to the top contains a great quantity of black shale with plant impressions.

At Payne's mine a clay from 4 to 6 inches thick underlies the coal. The upper half inch to 4 inches is a soft, dark shale and the lower 1 to 2 inches is a soft yellow clay.

The floor of the Felker mine is a soft shale, sagger clay. It is irregular in thickness, but averages from 4 to 5 feet. In some places in the mine this clay overlies the coal to a thickness of from 2 to 4 inches.

One mile northwest of Knoxville, on the Little Rock and Fort Smith Railway, the railway grade cuts a promising-looking exposure of shales.

At Hartman station the railway has exposed the shales in a cut.

In sec. 32, T. 10 N., R. 23 W., in the bank of the stream that runs south along the east side of the road near Clarksville College, the following section is exposed:

Section in sec. 32, T. 10 N., R. 23 E.

	Ft.	In.
1. Dark-brown shale	2	
2. Disintegrated shale	1	4
3. Coal		1
4. Blue and snuff-colored shales (about)	15	
5. Black shales at the base.		

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The following is an analysis of some of the clay produced by the disintegration of Nos. 1 and 2 of the above section, obtained from ditch at W. J. James's, in the southeast corner of the NW. ¼ SE. ¼ sec. 32, T. 10 N., R. 23 W.:

Analysis of distintegrated shale from sec. 32.

[Brackett & Smith, analysts.]

Silica (SiO_2)	55.36
Alumina (Al_2O_3)	26.96
Ferric oxide (Fe_2O_3)	5.12
Lime (CaO)	.30
Magnesia (MgO)	1.16
Potash (K_2O)	2.69
Soda (Na_2O)	1.03
Loss on ignition (water)	7.90
	100.52
Water at 110°–115° C	3.90

A specimen of blue clay shale overlying a 2-inch bed of coal collected by Mr. William Kennedy northwest of Clarksville in the SE. ¼ SW. ¼ sec. 31, T. 10 N., R. 23 W., has been analyzed by the Arkansas Geological Survey.

Analysis of disintegrated shale from sec. 31.

[Brackett & Smith, analysts.]

Silica (SiO_2)	51.30
Alumina (Al_2O_3)	24.69
Ferric oxide (Fe_2O_3)	10.57
Lime (CaO)	.32
Magnesia (MgO)	.63
Potash (K_2O)	2.18
Soda (Na_2O)	.72
Loss on ignition (water)	9.11
	99.52
Water at 110°–115° C	4.92

The section exposed where this specimen was taken by Mr. Kennedy is given below, and the specimen analyzed was from No. 2 of the series.

Section in SE. ¼ NW. ¼ sec. 31, T. 10 N., R. 23 W.

	Ft.	In.
1. Waterworn gravels	1	
2. Blue and yellow shales	8	
3. Coal		2
4. Blue shales with red streaks	4	
5. Black shales at base of section.		

The abundance of clays and clay shales in Johnson County and their proximity to good coal and to transportation both by railway and by water insure facilities for the extensive manufacture of paving bricks, sewer pipes, and fire-clay products.

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BRICK CLAYS.[a]

So far as the Clarksville brick earths are concerned, there is but one bed that requires attention. Bricks were formerly made by W. P. Farrish in his yard north of the town, in the northeast corner of the SW. ¼ NW. ¼ sec. 32, T. 10 N., R. 23 W. These appear to be good sound bricks of a rather dark-gray color, very similar in appearance to the bricks made at Beebe and elsewhere along the Iron Mountain Railway. They hold their color well, for bricks used in buildings erected in Clarksville as long ago as 1878 still have a good color. The material from which these bricks were made is not very plentiful nor of a great extent, being confined principally to the flat tops of a few ridges. It is underlain by a lighter-colored earth containing great quantities of iron in the form of nodules ranging in size from that of a pea down to that of bird shot. This underlying material, although of excellent quality for making hard, blue bricks, can not be worked by hand in the same way as the upper clays. The iron nodules are so small that the ordinary mill or wheel will not crush them. They slip through the tempering untouched, and, although not very hard, have a tendency to tear the hands of the molder. Before this clay can be utilized it must be tempered by being passed through rollers set sufficiently close to crush the nodules completely. The clay must afterward be thoroughly mixed so as to disseminate the crushed iron throughout the mass, and thus to bring the whole to a uniform consistency and color. The bricks can then be formed either by hand molding or by machine. This clay, however, could be worked better by machine than by hand, and if such a tempering machine as the one here suggested were used an extensive area covered by this "buckshot" clay close to Clarksville station could be utilized for brickmaking.

No bricks have been made at Coal Hill and very few are used for any purpose, building stone being generally employed for chimneys or other mason work.

In the vicinity of Coal Hill an area comprising the NE. ¼ S. ½ sec. 20, the greater portion of sec. 21, the SE. ¼ and part of the SW. ¼ sec. 19, and parts of secs. 28, 29, and 30, T. 9 N., R. 25 W., are covered by a light brownish-yellow clay averaging about 2 feet in thickness. This clay contains nodules of iron, some of which are soft enough to be crushed between the fingers, and also a quantity of small sandstone pebbles. This clay rests upon soft, friable argillaceous shales having a light-gray, almost white color, streaked with black and red. The lowest shales exposed are black and friable.

Overlying the light brownish-yellow clay there are in places patches or rolls of a brown sandy loam suitable for molding sand. These

[a] Most of the notes on the brick clays of Johnson County are by William Kennedy.

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patches, however, are not very thick nor of great extent. Their longer axes generally have a north-south direction.

The following section shows the relation of the clays and shales of low grounds about Coal Hill:

Section near Coal Hill.

	Feet.
Brown sandy loam	1
Brownish-yellow clay with iron nodules and small sandstone pebbles.	2
Shales with iron-stained streaks	4
Black shales at base.	

No establishments engaged in the manufacture of clay products in Johnson County are at present reported.

LAFAYETTE COUNTY.

Lafayette County lies almost wholly in the alluvial plain of Red River. The geology of these alluvial lands is as a rule less interesting than that of the higher country east and west. There is, however, a strip 6 or 8 miles wide running along the extreme eastern border of the county that has the same geology as Columbia and southern Hempstead counties, and in this region the Tertiary clays are likely to be found. In the vicinity of New Lewisville the cuts along the railroad expose no clay beds that appear to be of importance. Near Bradley station a well put down on the land of H. Smith, in the NW. ¼ sec. 13, T. 19 S., R. 25 W., has the following record:

Section near Bradley station.

	Feet.
Soil and sand	18
Red clay	9
Sand	10

About Walnut Hills are massive beds of red sand, but no clay beds were observed except bright-red ones. In the lowlands along Red River many local pockets of leached pottery clays and extensive beds of good brick clays may be found.

There are no industries of any kind in the county engaged in the manufacture of clay products.

LAWRENCE COUNTY.

GENERAL GEOLOGY.

Black River marks the boundary between the Paleozoic and Quaternary deposits of Lawrence County. The Quaternary area is a level plain having a maximum elevation of about 280 feet and a minimum of about 250 feet.

The streams all flow southwestward, roughly parallel to Black River, and narrow clay flats lie between the streams and the river. The soil adjacent to the streams is of alluvial origin, covering areas

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from 1 to 3 miles wide on both sides of the streams. The interstream area is a yellow hardpan or clay. In the lower lands the clay has become leached, leaving the surface material a lifeless buckshotty clay land known as "glades." The soil is very poor and but little of it is under cultivation. Water stands on some parts of this land for several months of the year. The character of the strata found at Walnut Ridge is shown in the following well record at that place:

Well record at Walnut Ridge.

	Feet.
Yellow to white clay	16
Fine sand	4
Hardpan similar to surface stratum	6
Fine black sand	5
Red sand, coarse	5
Coarse sand and gravel down to 65 to 70 feet.	

The white clay land extends eastward from Walnut Ridge to Sedgwick, on Cache River. The country to a line within 3 or 4 miles of Cache River, is marked by a rolling surface, with an occasional abandoned water channel.

The following is the general record of the strata in wells at Sedgwick:

General section of wells in Sedgwick.

	Feet.
Soil and clay	3– 6
Hardpan	3– 5
Black sand, water bearing	25–50
Hardpan or clay	2– 3
White sand, water bearing, to 65 feet.	

Just east of Sedgwick there is an area of lowland depressed 6 to 10 feet below the general level, marking the present limits of Cache River bottom, which is about 1 mile wide.

West of Walnut Ridge the country is mostly sandy, except the clay ridge on which Portia is situated, but over all the sandy region the older clay loam appears at the surface in places and forms the subsoil beneath the alluvial sand.

The following is a section of the strata in the east bank of Black River, at Cloverbend, about 9 miles south of Powhatan:

Section in bank of Black River at Cloverbend.

	Feet.
White buckshot clay, very hard when dry	3
Reddish tinted clay, very hard when dry, becoming sandy at base.	3
Reddish stratified sand, rather fine	3
Light-colored gray sand, stratified; coarser than the above	3

The sand is said to extend down to a depth of at least 50 feet below the surface.

The country west of Black River rises 200 feet or more above the bottom lands east of the river. The rocks belong to Cambro-Ordo-

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vician series, and are composed of heavy-bedded, dark-colored limestone and of sandstone which is doubtless the equivalent of the St. Peter sandstone in southwest Wisconsin and Missouri.

CLAY INDUSTRY.

In Lawrence County there is but one plant in the Quaternary area that is engaged in the manufacture of clay products. This is Moore & Co.'s brick plant at Walnut Ridge, where common soft-mud bricks are made.

The surface white clay, to a depth of 6 feet, is used for making the bricks. The clay is tempered and molded in a Monarch pug mill, dried in covered racks, and burned in up-draft kilns. It requires three to four days for drying and ten to twelve days for burning. A light fire is kept under the bricks for five to six days, and a hot fire for about the same length of time. Wood is used exclusively for fuel. The bricks are dried and burned without checking. Wheelbarrows are used to convey the green bricks from the molds to the racks and the dried bricks from the racks to the kilns The bricks have a shrinkage of about one-eighth of their volume. The output of the plant is about 1,500,000 bricks per annum. The market for the bricks is Walnut Ridge and the surrounding towns.

There are two common mud-brick plants in the hard-rock district, one at Black Rock and the other at Imboden. The clay used at Black Rock is the yellow or reddish clay, doubtless of the same age as the yellow loam that occurs on top of Crowleys Ridge. The plant at Imboden uses the residual clay of the older rocks.

LEE COUNTY.

GENERAL GEOLOGY.

Lee County is crossed near its center by Crowleys Ridge, which extends in a north-south direction. In the northern part of the county L'Anguille River has cut through Crowleys Ridge and joins St. Francis River about 6 miles southeast of Marianna. North of this L'Anguille River flows in the flat lands on the west side of the ridge and parallel to it. The eastern portion of the county is low bottom land, largely built up of deposits of St. Francis and Mississippi rivers.

The typical calcareous loess forms the top and sides of Crowleys Ridge in Lee County. On the lower slopes on the west side of the ridge there is a kind of terrace or second bottom which is several feet higher than the flat, wet lands farther west. This terrace is very regular in elevation and extends entirely along the foot of the ridge except where it has been cut away by streams. The soil of this second bottom or bench is a light brown or yellow loam, the reworked product of the loess, and is well adapted to the manufacture of bricks.

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The country between Marianna and the Lonoke County line is a rolling plain cut into north-south ridges, with low, wooded depressions. The surface of many of these low ridges is a clay loam similar to the surface material on the terrace adjacent to Crowleys Ridge.

CLAY DEPOSITS.

Only one analysis has been made of the surface clays of Lee County, the sample being a reworked product of loess found at the foot of Crowleys Ridge at Marianna. The bricks made from this clay are of a deep-red color, and form a good, strong building brick.

Analysis of reworked loess soil from near Marianna, in sec. 24, T. 2 N., R. 3 E.

[Dried at 110°–115° C. R. N. Brackett, analyst.]

Silica (SiO_2)	75.46
Alumina (Al_2O_3)	10.29
Ferric oxide (Fe_2O_3)	7.07
Lime (CaO)	1.00
Magnesia (MgO)	1.36
Potash (K_2O)	.74
Soda (Na_2O)	.82
Phosphoric acid (P_2O_5)	.30
Loss on ignition	3.18
	100.22
Air-dried sand	72.40

This material is of chocolate-brown color and fills the bottoms and ravines of the region east of Marianna. It seems to be a rearranged and highly ferruginous variety of loess, agreeing with ordinary loess in all other particulars.

CLAY INDUSTRY.

A plant for the manufacture of common building brick was established in Marianna about 1890. It is at present run by O. C. Sutton & Co. The bricks are made from the red surface clay. The clay is tempered and molded in a steam machine having a capacity of 25,000 to 30,000 bricks a day. The bricks are dried by the rack and pallet system, in covered sheds. It requires about seven days to dry the bricks sufficiently for setting in the kilns. Wood is the fuel and the bricks are burned about nine days. Three up-draft clamp kilns are used. About half a cord of wood is consumed in burning a thousand bricks. The size of the bricks is $8\frac{3}{4}$ by $4\frac{1}{8}$ by $2\frac{1}{4}$.

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LOGAN COUNTY.

GENERAL GEOLOGY.

The rocks of the northern half of Logan County belong to the upper coal-producing part of the Carboniferous, while those of the southern half of the county, except the top of Magazine Mountain, lie below the coal. The general geology of the county is like that of Sebastian, Franklin, Johnson, and Pope counties, and the clays and clay shales are very similar to if not identical with those of the counties named.

CLAY DEPOSITS.

CLASSES OF CLAYS.

For convenience of presentation the clays of the county may be classified as follows:

1. Carboniferous clays and clay shales associated with the coal and interbedded with the hard rocks.
2. Buckshot clays or brick loams, found in the uplands.
3. Terrace or second-bottom clays, found along Arkansas River.
4. River-bottom clays of the flood plains of the large streams.

These will be taken up in the order in which they are enumerated.

CARBONIFEROUS CLAYS AND SHALES.

Many of the clays associated with the coal beds of Logan County are fire clays. Some of these beds are only a few inches thick and of limited areal distribution, but it is to be expected that many fire-clay beds of workable thickness will be found associated with the coal. Such clays underlie the coal in the NE. ¼ NE. ¼ sec. 10, T. 7 N., R. 26 W., at the coal opening of H. M. Nichols. This clay is soft, dark blue, streaked with yellow, and only from 6 to 8 inches thick. The miners report that it is not a constant bed. At Wall's slope, in the NE. ¼ NW. ¼ sec. 15, T. 7 N., R. 26 W., a similar clay lies beneath the coal bed, but the mine being full of water, its thickness was not determined.

On the north side of the NW. ¼ NE. ¼ sec. 34, T. 8 N., R. 26 W., two beds of clay are exposed in the channel of a small stream. The upper bed is a dark-brown clay about 3 feet thick; the lower bed is of a lighter yellowish color. Only about a foot of the lower bed is exposed, but it is probably not less than 7 or 8 feet thick. The lower bed is said to have been used as a fire clay. A sample of this lower bed has been analyzed:

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Analysis of clay from sec. 34, T. 8 N., R. 26 W.

[Brackett & Smith, analysts.]

Silica (SiO_2)	88.66
Alumina (Al_2O_3)	5.73
Ferric oxide (Fe_2O_3)	2.55
Lime (CaO)	Trace.
Magnesia (MgO)	Trace.
Potash and soda (K_2O, Na_2O)	.81
Loss on ignition	2.25
	100.00
Water at 110°–115° C	1.33
Sand in clay dried at 110°–115° C	17.94

Clays of this class are widely distributed over Logan County, and these examples do not fairly represent them either in thickness or importance. The Carboniferous clay shales are so abundant, so thick, and so widespread in Logan County that only a few typical areas will be mentioned.

In the southwest corner of the county the line between Logan and Scott counties crosses Jennings Hill. The alternate series of sandstones and shales forming this hill is described under the heading "Scott County." The same beds extend from Jennings Hill toward Booneville, a distance of 5 miles. The most important shale of this group underlies the town of Belva, in Scott County, but it crosses into Logan County in the NW. ¼ sec. 30, T. 5 N., R. 28 W., runs northeastward for 5 miles, and swings westward along the valley of Petit Jean Creek. This shale is 200 to 400 feet thick at Belva. Below this shale are two beds of sandstone and a thinner bed of shale, followed below by a thicker bed of shale.

A thick deposit of shale near the top of the Atoka formation covers a large area in Logan County and extends also into the adjacent counties both east and west. It ranges in thickness from 400 to nearly or quite 2,000 feet. It is generally of dark color, and although it is usually a clay shale it is at some places sandy. Starting in the southwest corner of the county near Golden City, this shale and its accompanying beds of coal form the surface rock along the upper parts of the valley of Brashy Branch and extend down Fletcher Creek toward the town of Booneville, and thence down the valley of Petit Jean Creek to Magazine. West of Booneville the same shale runs through the northern tier of sections in T. 5 N., R. 28 W., to Barber post-office. East of the town of Magazine the outcrop of this shale divides, one arm of it passing south of Magazine Mountain and underlying the northern part of the northern tier of sections across T. 5 N., R. 25 W., and the southern tier of the township just north of it. The same shale lies along the

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south base of the range of mountains connecting Magazine Mountain with Mount Nebo in Yell County. Northeast of the town of Magazine these shale beds run northeastward for about 7 miles and then bend abruptly westward to the gap between Brushy Mountain and Calico Mountain. From this point they extend both east and west, with narrower outcrops. The outcrop to the east extends around the north base of Magazine Mountain and then around the base of Huckleberry Mountain, Three Knob Mountain, Spring Mountain, and Mount Nebo. Where the shale beds run around the north sides of the bases of these mountains they are either nearly horizontal or have a gentle southward dip and pass beneath the mountains, to appear again to the south of them. North of the mountains the rocks are folded, passing over an anticline and then dipping northward. The shale therefore appears again north of the anticlinal fold across the entire east-west length of Logan County.

Starting in Yell County northeast of Mount Nebo the same shale underlies Dardanelle Ridge and extends along the south side of its western continuation in Pine Ridge as far as Wildcat Mountain, around which it passes, and runs along the north side of Brushy Mountain until it joins the outcrop in the gap east of Brushy Mountain. Another area of this shale lies between the village of Prairie View and Shoal Creek Ridge, in T. 8 N., R. 24 W. It is only about 5 miles long and less than 2 miles wide. The length of the outcrop of this great body of shale in Logan County thus aggregates fully 150 miles.

In Logan County there is a shale associated with the coal found near Blaine post-office and the village of Shoal Creek and extending thence eastward in Yell County. This same shale horizon runs along the south side of Snake Ridge in T. 8 N., R. 24 W.

The shales in the rolling country at Paris and farther west, to the county line as well as farther east, about Spielersville and Ellsworth, and farther north, to Roseville, belong to an overlying series of rocks associated with the upper coal beds. On the south side of Short Mountain these shales and the coal dip northward and pass completely beneath that mountain, rising to the surface again on the north side. On the sides of Short Mountain thick beds of shales are exposed. The geology of Little Short Mountain is the same as that of Short Mountain. The rocks pass beneath it, so that these two mountains stand in synclinal folds, whose beds are largely composed of clay shales.

It is evident that the Carboniferous clay shales cover an enormous area in Logan County. Unfortunately, no practical tests have been made of these shales, but in so far as the appearance of the materials can be depended upon they are almost everywhere

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available for the manufacture of paving brick, sewer pipe, and common earthenware, while many of them are true fire clays. With the exception already mentioned (pp. 128–129) no chemical analyses have been made of these clays. The analysis made, however, bears out the theory that the clays are workable, although they are not now utilized.

BUCKSHOT OR PRAIRIE CLAYS.

The clays found in the prairies are chiefly the altered edges of the shale outcrops. These clays have been used for the manufacture of building bricks, but the small iron nodules scattered through them cause the bricks to burn dark brown or spotted. The bricks are almost invariably strong and exceedingly durable, but they have not an attractive color.

In the neighborhood of Paris the clays are principally prairie soils, disintegrated blue shales, and the shales and clays associated with coal beds. Probably the most extensive of the prairie clay deposits is that of Hegwood Prairie. In the E. ½ SE. ¼ sec. 1, T. 7 N., R. 26 W., this prairie soil is yellow, contains a considerable quantity of iron nodules, and has an average depth of 2½ feet. In the NW. ¼ SE. ¼ sec. 1, T. 7 N., R. 26 W., a well 21 feet deep passes through yellow prairie soil 3 feet thick, which rests immediately on blue argillaceous shales of the coal-bearing rocks. In the NE. ¼ sec. 11 and NW. ¼ sec. 12 of the same township and range the yellow soil is somewhat deeper, but its general characteristics are the same. In the SW. ¼ SW. ¼ sec. 6 and the NW. ¼ NW. ¼ sec. 7, T. 7 N., R. 25 W., brick earths of the same yellow color are found, having an average depth of 3 feet. On the road along the south base of Short Mountain and in the SW. ¼ sec. 3, T. 7 N., R. 26 W., the blue shales appear in several places in a ditch on the south side of the road. These shales are 4 feet thick and are completely disintegrated where exposed. Similar clays occur in the valley about Booneville, in the upper bottoms of Sugar Creek, Petit Jean Creek, Revilee Creek, Shoal Creek, and other streams. None of these are utilized in Logan County.

TERRACE CLAYS ALONG ARKANSAS RIVER.

Clays similar to those found in the river terraces near Arkansas River at Fort Smith and at Argenta occur along the south side of Arkansas River in Logan County. These clays are generally sandy and of a reddish color, but wherever they have been tried they have been found available for the manufacture of fairly good building bricks. From Roseville a band of this red sandy clay forming a terrace or second bottom winds about the foothills south of the river bottoms. This terrace is crossed by the Roseville-Paris road just

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south of Short Mountain Creek. The clay of this terrace is similar to that at Argenta.

Chocolate-colored plastic clays are associated with these terrace clays. Thus far no use has been found for these chocolate clays.

RIVER-BOTTOM CLAYS.

The clays of the Arkansas River bottoms are pockety and of uncertain distribution. They are not likely to be of economic importance, though some of the lenticular masses may occasionally contain pottery clays.

LONOKE COUNTY.

GENERAL GEOLOGY.

Most of Lonoke County lies within the Quaternary area of the State. The country is so flat and unbroken that there are almost no natural exposures of the rocks east of the St. Louis, Iron Mountain and Southern Railway. The extreme northwest corner of the county is in the lower Carboniferous (Mississippian). This includes, however, only the part of the county lying west of the St. Louis, Iron Mountain and Southern Railway, an area of only 55 square miles. The geology in this Paleozoic corner is an eastward continuation of that of Faulkner County. The same beds that outcrop in the southeast corner of Faulkner County pass through the Paleozoic part of Lonoke County to a point where they are overlapped by the Coastal Plain beds near the present location of the St. Louis, Iron Mountain and Southern Railway. The rocks of the lower Carboniferous here consist of alternate beds of sandstone and shales, all of them folded. The ridges through this region are usually of sandstone and run almost due east and west. The shales are parallel with the sandstones and occupy nearly all of the valleys, and in many instances they also form the lower slopes of the ridges.

The Bayou Meto anticline, starting between Preston and Mayflower, in Faulkner County, runs due east toward the town of Austin, Lonoke County, passing through the northern tier of sections of T. 4 N., R. 10 W. North of this anticline as far as Cypress Bayou the rocks all dip northward, and south of it they all dip southward as far as the Cato syncline, which passes through sec. 30, T. 4 N., R. 10 W. These dips of the rocks should be borne in mind in any attempt to utilize the clay shales of this area.

CLAY DEPOSITS.

The clay shales, like those of other parts of the State, vary considerably in character. Some of them are so sandy that it is difficult to determine whether they should be considered clayey sandstones

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or sandy shales; others contain but little sand, and are sufficiently refractory to be regarded as fire clays. The shales are in places decomposed along their outcrops, but for the most part they are too hard to be pugged as they come from the ground. Analysis of some of these shales shows them to be suitable for the manufacture of paving brick, sewer pipe, fire bricks, or other refractory goods, but they will require to be pulverized.

The character and thickness of these shales, their proximity to the railroad, and the topography of the region are all favorable to the development of important clay industries in this section of Lonoke County.

In addition to the shales there are widespread beds of loam over the slashes or bottoms of Cypress Bayou, Magness Creek, and Wattensas Bayou. The loams are well adapted to the manufacture of common building bricks. In places they contain some buckshot clays, and are therefore not suitable for making high-grade finishing bricks. The bands of buckshot or iron nodules occur here and there at a depth of from 1 to 4 feet from the surface.

The wells at Austin and Cabot penetrate fossiliferous Cretaceous sediments, which outcrop in a few places west of these towns.

What has been said of the Beebe, Kensett, and West Point clays of White County is generally applicable to the clays along the railroad at and near Holland, Cabot, Austin, and Ward.

Two wells near Cabot show the presence of the light-colored clay.

At Neeley & Neeley's gin house in the village of Cabot a well 116 feet deep has the following section:

Section in well at Neeley & Neeley's gin house, Cabot.

	Feet.
Red and sandy clays	39
Calcareous clay (Cretaceous)	1
Marl (Cretaceous)	6
Carboniferous shale to the bottom of the well	70
	116

A well near the center of the NE. ¼ SW. ¼ sec. 25, T. 4 N., R. 10 W., passes through the following beds:

Section in well in sec. 25, T. 4 N., R. 10 W.

	Feet.
Soil	2
Red clay	10
Sandy clay	16
Calcareous clay (Cretaceous)	1
Marl (Cretaceous)	8
Carboniferous shale at bottom.	
	37

The clay here marked "red clay" is mottled red and gray, resembling very closely that underlying the low Quaternary country at different places.

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The average well section at Lonoke, as reported by J. C. England, is as follows, the section being that of an open well:

Average section in wells at Lonoke.

	Feet.
Red clay	5– 6
White clay grading into sand	5– 6
Bluish, mucky, sticky clay.	
Quicksand, all the way from	30–45
Tough clay.	

Wells that reach to a depth of 70 to 80 feet get into gravel. A specimen of this gravel was brought to the office of the Arkansas Survey. It is composed mainly or entirely of waterworn chert pebbles, about the size of a hazelnut, and coarse quartz sand.

The average depth of bored wells at Lonoke is 70 to 85 feet. The deepest well reported is at J. C. England's place and is 107 feet deep.

CLAY INDUSTRY.

Chaplin & England's brickyard.—In the NE. ¼ SW. ¼ sec. 19, T. 2 N., R. 8 W., bricks were once made at the yard of J. P. Chaplin and E. W. England from a mixture of about 18 inches of the top yellowish prairie soil and about the same thickness of a brown iron-stained earth underlying the prairie soil. The bricks are hard and showed a tendency to melt when raised to a high temperature in the kiln. Those that were burned hard have a brown color and are very much spotted with dark, almost black marks. In bricks burned near the center of the kiln the color is a dark cherry red, the spotting is not so prominent, and in many of the bricks the spotting is not visible at all. There was not much loss on account of breaking in the burning. The bricks were machine made.

Harrison Brick Company.—This is the only plant now in operation in the town of Lonoke. It is quite likely, though it is not an assured fact, that this plant is the successor to the Chaplin & England plant. The Harrison plant was established in 1903, and is engaged in the manufacture of common building brick. It has an output of 25,000 bricks a day. The bricks are made from the red surface clay, molded in a steam machine, dried in the open air, and burned in up-draft clamp kilns. When the weather is favorable the bricks will dry sufficiently in three days to stand setting in the kiln. The bricks are burned with wood. About eight days are required to complete the burning. Two kilns are in use, each having a capacity of 175,000.

Wylie's plant.—There is also a brick plant at Cabot, on the St. Louis, Iron Mountain and Southern Railway. It is operated by I. C. Wylie. No further particulars concerning this plant were learned.

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MILLER COUNTY.

GENERAL GEOLOGY.

Miller County is entirely within the Tertiary-Quaternary area. The beds everywhere penetrated by wells are Tertiary. Some of them contain marine fossils and others plant remains. Prof. William Moseley, at one time teacher at Texarkana, reports that a fossil palm was found in a well near Texarkana.

CLAY DEPOSITS.

Over the flooded regions of Miller County the soils are in some places alluvial, in others boggy slashes, and in others buckshot clays. The clays of the surface slashes are at many places leached clear of iron by the action of organic acids and carbonic acid, so that these clays are available for the manufacture of the coarser grades of pottery. This leaching, however, is a surface phenomenon, and such clays are nowhere more than 3 or 4 feet deep.

The nature of the surface, with the exceptions just mentioned, has nothing to do with the existence or nonexistence of pottery clays in the stratified beds below. The presence of such beds is seldom indicated by natural agencies in a flat region, where erosion is very slight, so that the existence, thickness, and character of clay beds must usually be determined by testing augers or pits, by digging wells, or by other artificial means.

The higher Tertiary lands about Texarkana occupy T. 15 S., R. 28 W., and a little of the adjoining territory. It is within this area, and principally in the northern tier of sections, that the pottery clays are worked. The occurrence of these clays on the north side of this higher region and the general southeastern dip of the Tertiary rocks of this area suggest that the pits now worked are at or near the northern outcrop of the Tertiary pottery clays and that these same beds dip beneath Texarkana. At what depth they lie beneath that city, however, can be determined only by ascertaining the dip of the strata.

Clay is obtained in a series of small openings in the west side of the SE. ¼ sec. 5, T. 15 S., R. 28 W.

The section exposed is as follows:

Section in sec. 5, T. 15 S., R. 28 W.

	Feet.
Iron-stained sandy clay	3
Whitish blue clay	5
Yellowish sandy clay at bottom.	

The middle bed of 5 feet is a pottery and fire-brick clay. The lower yellow sandy clay was tried for brickmaking purposes, but owing to some defect in the work rather than to the material used the attempt was unsuccessful.

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The clay burns to a solid cream-colored body. It admits of both a salt and "Albany slip" glaze. Fire bricks made from this clay are of a light color.

The following are the analyses of these clays:

Analyses of clays from sec. 5, T. 15 S., R. 28 W.

[Sample dried at 110°–115° C.]

	Sandy clay at the bottom.	White clay used for pottery.
Silica (SiO_2)	74.76	75.99
Alumina (Al_2O_3)	13.96	16.12
Ferric oxide (Fe_2O_3)	3.44	1.35
Lime (CaO)	.51	
Magnesia (MgO)	1.10	1.45
Potash (K_2O)	2.28	
Soda (Na_2O)		
Loss (H_2O)	3.95	5.09
	100.00	100.00
Sand in air-dried specimen		.75
Water at 110°–115° C	3.33	1.08

CLAY INDUSTRY.

Kind of clay used.—There are two brick plants and one stoneware pottery in Miller County. The clay used for the manufacture of fire brick and stoneware comes from the Tertiary clays, which are doubtless of the same age as those used at the Benton pottery, situated in sec. 9, T. 15 S., R. 28 W. In one of the pits clay was formerly obtained for the manufacture of stoneware. A sample of clay from this pit was analyzed:

Analysis of clay from sec. 9, T. 15 S., R. 28 W.

Silica (SiO_2)	74.85
Alumina (Al_2O_3)	17.20
Ferric oxide (Fe_2O_3)	1.12
Magnesia (MgO)	1.13
Loss on ignition	5.70
	100.00
Sand in air-dried specimen	3.44
Water at 110°–115° C	1.53

Texarkana Brick Company.—At the plant of the Texarkana Brick Company, established in 1902, dry-pressed bricks are made from a semishale or clay. These bricks are molded in a Boyd dry-press machine and burned in up-draft clamp kilns. Five kilns are in use, each of which is 23 by 59 by 14 feet, inside measurements. Wood and oil are used for burning. The bricks are water-smoked for about ten days without wood and then a hot fire is kept up for about ninety hours. Oil is used for making the hot fire. The size of the green bricks is 8⅞ by 2⅜ by 4¼ inches. The bricks have a shrinkage of about

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one-sixteenth after burning. The output of the plant is 20,000 bricks a day.

Steven brick plant.—No data have been obtained concerning the brick plant of Anthony W. Stevens, located in Texarkana.

Interstate Pottery Company.—The plant of the Interstate Pottery Company is located at Texarkana. The clay used is the Eocene (Tertiary) clay similar to that used near Benton by the Eagle Pottery Company. Jugs, churns, and jars are made.

MISSISSIPPI COUNTY.

Mississippi County occupies the northeastern corner of the State and is bordered by Mississippi River. The entire county is low and is subject to overflow by the river. The lowest lands are covered with water throughout the year. There are many large lakes in the southern, western, and northern portions of the county. Some of these lakes, such as Big Lake and Tyronza, are several square miles in extent. Levees along the entire Mississippi front are necessary to keep out the flood waters in the spring of the year. The highest land in the county is along Mississippi River, which by repeated overflows has deposited its greatest load on lands nearest the main channel. The westward slope of the country is shown by the fact that many small streams head near Mississippi River and flow westward and drain into Tyronza River and Pemiscot Bayou.

Much of the surface of the county is composed of alluvial deposits of silt, sand, and finely divided clay. In places, however, beneath the alluvial sand there is a yellow clay loam which greatly resembles the yellow clay loam of the prairies west of Crowleys Ridge and the narrow strip of clay land on the east side of the ridge. In a few places the yellow loam forms the surface soil.

At some distance back from the streams and abandoned water courses the country becomes flatter and is now largely covered with water for several months in the year. This land in the interstream areas is a gray buckshotty clay land, covered with a dense growth of sycamore, gum, and cottonwood, with more or less maple, willow, oak, hickory, black oak, elm, and ash. In the buckshotty clay area there are no signs of old stream channels.

At Blytheville there is a brick and tile works plant which makes a common brick from the yellow surface clay loam. The buckshot clay could likewise be tempered with sand and utilized for making common brick.

NEVADA COUNTY.

The geology of Nevada County is like that of Dallas and Ouachita counties, to the east and north, like that of southern Hempstead County, to the west, and like that of Columbia County, to the south.

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In Nevada County, however, no large streams cut deep into the soft strata as the Ouachita cuts into those in Ouachita County, so that good exposures of the clay beds are rare and little or nothing is known about them. The strata of this county are nearly horizontal but dip slightly toward the southeast, and therefore a good clay bed found anywhere in the county will probably lie deeper beneath the surface as one follows it southward.

Records should be made of clay beds passed through by wells, for a promising clay found in a well may come to the surface at some point farther northwest. It is not likely that good pottery clays will be found close to the St. Louis, Iron Mountain and Southern Railway, but valuable and abundant brick clays may be found near that road. The best pottery clays and clays available for refractory purposes will be found about the central and southeastern part of the county.

Only one establishment in Nevada County is engaged in the manufacture of clay products, Longston Brothers' common-mud brick plant, located at Emmet, with an office at Sutton.

OUACHITA COUNTY.

GENERAL GEOLOGY.

The geology of Ouachita County may be regarded as typical of the southern portion of the State. The surface is underlain entirely by rocks of Tertiary age except where they have been removed by denudation and the valleys filled with Quaternary alluvium or residuary accumulations. The Tertiary rocks are usually not very hard; they are clays, sands, lignites, and gravels, and these four at many places grade into one another, forming sandy clays, clayey sands, lignitic clays, and all other possible combinations. At some places the sands are indurated, forming hard quartzites; at others they are but loose sands; while in color they range through the browns, yellows, grays, and reds.

Though local dips may be seen, most of the rocks lie in horizontal or approximately horizontal beds, so that they may readily be traced from one locality to another.

The Tertiary beds have been cut by Ouachita River, which has washed out a wide valley. This valley is bordered on the west by a rather abrupt escarpment, in which the Tertiary beds outcrop, especially at points where the river hugs its right bank, as at Camden, Newport Landing, and Millers Bluff.

In Camden a steep-sided ravine having walls 40 feet high is cut in the soft sandy clays by the stream.[a] A large part of the exposed surface of these clays was at one time covered with an abundant

[a] The section exposed on the Ouachita at Camden is given in Ann. Rept. Geol Survey Arkansas for 1888, vol. 2, p. 50.

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efflorescence of green vitriol (ferrous sulphate) derived from the clays. This green vitriol causes the peculiar taste of the water found in many of the wells at Camden.

The character and disposition of the Tertiary beds at Camden may be taken in a certain sense as typical of the geology of Ouachita County. The strata there exposed extend beneath the whole county, but in a more or less modified form. This variability of the strata interrupts, of course, the continuity of the clay deposits and of whatever else there may be of economic value in these beds. The sandy clays, for example, in their horizontal distribution give place to pottery clays, and pottery clays give place to brown coal, and brown coal gives place again to clays or sands or some of the other beds so common throughout the county.

In some places the beds are deeply eroded and broad valleys are formed in them, so that the strata for several miles have been washed away, clays, sands, coals,[a] and all. The valley of the Ouachita is itself an example of such erosion. The road from Lester station,

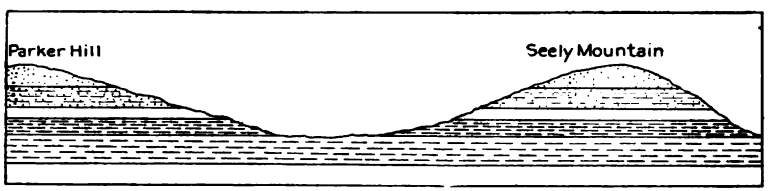

FIG. 12. - Section of Parker Hill and Seely Mountain, Ouachita County.

on the Camden branch of the St. Louis, Iron Mountain and Southern Railway, to Camden passes over a sharp ridge called Seely Mountain, which rises about 200 feet above the level of the Ouachita bottoms. About 4 miles northwest of Camden the same road ascends Parker Hill, which is geologically a repetition of Seely Mountain and which has the same elevation, the two being separated by a broad valley which has been cut out by the ordinary process of erosion. The profile section in fig. 12 will make plain the relations of these ridges to each other.

These details of general structure are given for the purpose of showing how the distribution of clays in Ouachita County is determined by the geology of the region.

CLAY DEPOSITS.

The region in which the brown coals occur is a promising one in which to seek valuable clays both for the manufacture of pottery and for fire clays.

[a] The Geological Survey of the State has data for a report on the coals of Ouachita County, and the United States Geological Survey has published a report on this subject by Mr. Joseph A. Taff in Twenty-first Ann. Rept , pt. 2, 1900, pp. 319-329.

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In the S. ½ SE. ¼ sec. 2, T. 12 S., R. 18 W., on a small stream called Sandy Branch, is an exposure of material that has received considerable attention. It has the appearance of being a very sandy, compact, nonplastic, whitish cream-colored clay. It has usually been regarded as a fire clay, but the percentage of water of crystallization contained in the material when freed from sand shows it to be a kind of kaolin.

This bed is exposed inconspicuously at three or four places on Sandy Branch, at the base of the hills that form the western limit of the immediate valley of Ouachita River. Most of the outcrop is concealed by débris that has fallen down from the hills above, but it has been opened sufficiently to show its relation to the overlying beds and to expose a thickness down to the water of Sandy Branch of 12 feet, but without discovering the total thickness of the deposit.

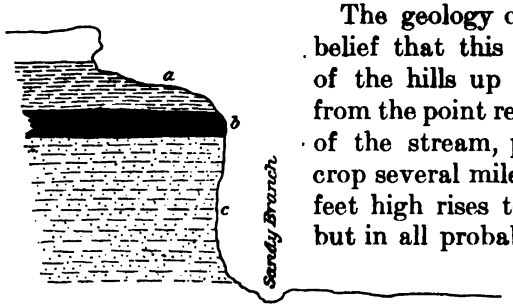

FIG. 13.—Section on Sandy Branch, near Ouachita River, Ouachita County. *a*, Plastic clay; *b*, brown lignite; *c*, sandy kaolin.

The geology of the region leads to the belief that this material lies at the base of the hills up and down Sandy Branch from the point referred to and on both sides of the stream, probably forming an outcrop several miles long. A hill nearly 100 feet high rises to the west of the outcrop, but in all probability places may be found at which there is no considerable covering to the bed. At the exposure referred to a bed of brown lignite[a] about 3 feet thick overlies the clay, and above this is a bed of plastic clay, the thickness of which is not exposed.

Fig. 13 is a section at this locality.

The following is an analysis made by the St. Louis Sampling and Testing Works of a sample said to have been taken from this kaolin bed. It was kindly furnished by Dr. A. S. Garnett, of Hot Springs, who had the analysis made in August, 1889:

Analysis of kaolin from Sandy Branch.

Silica (SiO_2)	66.25
Alumina (Al_2O_3)	25.35
Sesquioxide of iron (Fe_2O_3)	.22
Lime (CaO)	.26
Magnesia (MgO)	Trace.
Alkalies	.84
Water and loss	7.32
	100.24

[a] As a rule this lignite is considerably thinner on the outcrop than inside.

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The following is an analysis of a sample of material said to have come from "Red Hill," made in 1882 for Walter Hamilton, of 120 William street, New York City, by A. Guyard, chemist. The material seems to be the same as that found in the Sandy Branch exposure.

Analysis of kaolin from Red Hill.

Silica (SiO_2)	70.40
Alumina (Al_2O_3)	18.40
Peroxide of iron (Fe_2O_3)	1.25
Titanic acid (TiO_2)	.05
Manganese (MnO)	Trace.
Lime (CaO)	.55
Magnesia (MgO)	.25
Alkalies	Trace.
Sulphuric acid (H_2SO_4)	.25
Water (H_2O)	8.75
Loss	.10
	100.00

A sample collected by the State Geological Survey of Arkansas (through Arthur Winslow, assistant geologist) at the Sandy Branch locality was analyzed by the Arkansas Survey. The label with this specimen says it comes from the NW. ¼ SW. ¼ sec. 2, T. 12 S., R. 18 W. Whether it came from that locality or from the one on Sandy Branch, the material is the same.

Analysis of kaolin from sec. 2, T. 12 S., R. 18 W.

[Brackett & Smith, analysts.]

Silica (SiO_2)	76.21
Alumina (Al_2O_3)	16.00
Ferric oxide (Fe_2O_3)	.75
Lime (CaO)	Slight trace.
Manganese and alkalies (by difference)	1.06
Water on ignition (H_2O)	5.98
	100.00

Anyone examining this material is impressed by the fact that it contains a large percentage of sand, though, of course, samples can be selected that are comparatively free from sand. In order to determine the nature of the material when freed from the greater part of the coarse sand, a sample of it was washed. The following is the analysis of a sample of the washed material, the sand being deducted from the silica and the composition recalculated:

Analysis of washed kaolin from sec. 2, T. 12 S., R. 18 W.

Silica (SiO_2)	28.47
Alumina (Al_2O_3)	48.00
Ferric oxide (Fe_2O_3)	2.25
Magnesia (MgO) and Alkalies	3.18
Water (H_2O)	17.84
	99.84

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This shows that this material is simply a sandy kaolin and not an ordinary clay, in the chemical sense of that term.

After the sand is removed by washing it is available for the manufacture of pottery and also as a refractory material. As a fire clay it will be spoken of elsewhere in this report. The quantity of this kaolin in the vicinity of the locality described above seems to be very large. Mr. Winslow observed the following section in the NE. ¼ SW. ¼ sec. 2, T. 12 S., R. 18 W., under a bluff very like that observed by the writer on Sandy Branch:

Section in sec. 2, T. 12 S., R. 18 W.

	Ft.	In.
Sand and clay	6	
Decomposed lignite		8
Gray clay	1	6
Decomposed lignite	1	6
Sandy kaolin	12–15	

At this place also the full thickness of the bed is not seen.

It is reported from several places in sec. 36, T. 11 S., R. 18 W. At one point the former exposure is said to have recently been concealed by a landslide; at another place it is said to be 4 feet thick, and has been used for whitewash.

In the SW. ¼ NW. ¼ sec. 36, T. 11 S., R. 18 W., at the house of Jack McKinzie, the following section was passed through in digging a well:

Section in well in sec. 36, T. 11 S., R. 18 W.

	Feet.
Clay	2
Lignite	2½
Gray clay with sand	3+

There are thin beds of pottery clay on a branch of Wolf Creek at the mouth of a lignite drift in the NE. ¼ NW. ¼ sec. 14, T. 12 S., R. 18 W. These beds are only a few inches thick, and therefore too thin to be of any practical value. Inside the drift they are only 6 or 8 inches thick. It is possible that these beds may be thick enough in this neighborhood to render them valuable. The clay itself is of fair quality, as the following analysis of it shows:

Analysis of clay from NE. ¼ NW. ¼ sec. 14, T. 12 S., R. 18 W.

[Sample dried at 110°–115° C. Brackett & Smith, analysts.]

Silica (SiO_2)	79.42
Alumina (Al_2O_3)	13.35
Ferric oxide (Fe_2O_3)	2.17
Lime (CaO)	Trace.
Magnesia (MgO), Potash (K_2O), Soda (Na_2O)	Trace.
Loss on ignition (H_2O)	5.38
	100.32
Sand in air-dried specimen	9.48
Water at 110°–115° C	3.72

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In burning, this clay becomes a light gray and loses 9.68 per cent of its weight.

The following is the section exposed at the Sulphur Spring coal drift, at the base of the hill near the house of the superintendent of the Ouachita Coal Company's mines.

Section at Sulphur Spring coal drift.

	Ft.	in.
1. Yellow sand	15	
2. Thinly laminated sands and clay	7	
3. Sand		2
4. Buff pottery clay	1	6
5. Lignite	5	
6. Clay with fossil leaves	6+	

No. 2 of the above section is made up of interstratified half-inch beds of sand and pure clay, with fragments of vegetation scattered through them, in which form it can not be utilized. No. 4 is a good clay and might be utilized if the bed were thicker. Near the mouth of the drift it is somewhat stained with iron, but will not be found so stained farther in the hill. No. 6 is said to have been penetrated 6 feet in digging a sump in the coal mine, but at this depth it was not passed through. The leaf impressions in this clay are very abundant and fresh.

Mr. Winslow reports the following section from the old mine half a mile from the Ouachita River, in the NW. ¼ NE. ¼ sec. 12, T. 12 S., R. 18 W.

Section in old mine in NW. ¼ NE. ¼ sec. 12, T. 12 S., R. 18 W.

Sand on surface.	Ft.	in.
1. White sandy clay	3	
2. Chocolate sandy pottery clay	3	
3. Yellow and white sand	8	
4. Bluish-gray clay with sandy seams	8	
5. Carbonaceous shale		6
6. Lignite	5–6	
7. Gray clay not penetrated at	3	

No. 2 of the above section is a massive chocolate-colored clay that does not crack on drying. It seems to be available for the manufacture of both pottery and fire bricks. No. 7 is a tenacious pottery clay containing an abundance of well-preserved impressions of leaves. This bed strongly resembles the lower leaf-bearing bed of Atchison's pits at Perla switch, Hot Spring County, used for the manufacture of fire bricks.

The clays mentioned in this section are not being utilized for any purpose, although a company is said to have under consideration the question of erecting brick and sewer-pipe works in the neighborhood.

Mr. Kennedy reports also that at drift No. 1 on the Beach tract, within 200 feet of the county road, under the brow of a sandy hill,

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in the NE. ¼ NW. ¼ sec. 29, T. 12 S., R. 18 W., there is a bed of pottery clay about 2 feet thick overlying the lignite. The upper 6 inches of this clay is of a yellowish color; the lower 18 inches is bluish gray. Both portions contain a large amount of very fine micaceous sand. The gray portion seems to be a fair potter's clay.

Wells bored at Henry C. Bell's place on sec. 4, T. 13 S., R. 18 W., passed through an aggregate of 17 feet of clay and 4½ feet of lignite. The order of their arrangement could not be ascertained.

A well put down at Wilson Carter's gin in the NW. ¼ NW. ¼ sec. 15, T. 12 S., R. 19 W., has the following section:

Section in well at Wilson Carter's gin.

	Feet.
Sand	15
Clay	5
Lignite	4½
Clay.	

Mr. Kennedy reports a drift in the NW. ¼ NW. ¼ sec. 15, T. 12 S., R. 18 W., with 3 feet of blue-gray clay above and below a 3-foot lignite bed.

Near Dempay's mill, in the S. ½ SW. ¼ sec. 25, T. 12 S., R. 18 W., the road descending from the hills to the flood plain of Ecore Fabre Creek passes over some light-gray sandy clays that appear to be available for pottery. From this point the highlands that border the right side of the Ouachita Valley follow a zigzag course through secs. 25, 24, 13, 12, 11, 1, and 2 of T. 12 S., R. 18 W., and still farther north it passes through secs. 36, 35, 25, 26, 34, and 33, T. 11 S., R. 18 W., and returns to secs. 4 and 5 of T. 12 S., R. 18 W. The clay outcrops follow in and out around the sides of these hills, though as a rule they are concealed by the earth and humus that have accumulated upon them. Outcrops of the same beds may be traced in the same way about the headwaters of Wolf Creek and of Ecore Fabre Creek.

South of Ecore Fabre Creek the Lester-Camden road rises to higher ground in the NW. ¼ NW. ¼ sec. 1, T. 13 S., R. 18 W. In these higher lands good pottery clays crop out locally in gullies and in the bluffs, but for the most part the outcrops are concealed by débris from the overlying beds. In the SW. ¼ NW. ¼ sec. 1, near Joshua Lester's house, this clay is exposed on the hillside just west of the road. The section shows 2 or 3 feet of sandy clay with 2 feet (exposed) of pink sandy potter's clay beneath it. This clay contains fossil leaves.

Mr. Lester's house is in the NE. ¼ SW. ¼ sec. 1, T. 13 S., R. 18 W. Just across the road west of his house, and about 200 feet from it, there is a 3-foot bed exposed; above it the soil is streaked with red, and contains thin bands of limonite; below it are red sandy clays, over 15 feet of which are exposed.

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The sections exposed in Seely Mountain and in Parkers Hill, south of Lester, on the road to Camden, show very sandy beds, with no available pottery clays. These clays appear to lie at a lower level, and to wind in and out about the hills toward their bases.

In the city of Camden there is a small pockety bed of pottery clay, in places 3 feet thick, on the west side of the Missouri Pacific Railway, on California street.

The Arkansas Company, an organization with an office at Lester, Ark., owns a large part of the lignite and clay lands between the Camden branch of the St. Louis, Iron Mountain and Southern Railway and Ouachita River in T. 12 S., R. 18 W. This company put down a deep well at the center of sec. 12 of that township and range. Dr. A. S. Garnett, of Hot Springs, Ark., kindly furnished a copy of the record of this well, which shows the various clay beds and their thicknesses.

Record of well at the center of sec. 12, T. 12 S., R. 18 W.

	Feet.
Common clay	25
Blue fire clay	15
Coal (lignite)	5
Fire clay	15
Quicksand	60
Decomposed clay	5
Sand	30
Hard clay	30
Coal (lignite)	5
Hard clay	15
Sandy clay	110
Coal (lignite)	5
Sand and clay	50
Quicksand	100
Sand and clay	75
Hard clay	15
Coal (lignite)	10
Clay and sand	50
Coal (lignite)	2
Quicksand	175
Rock and sand	55
Total depth of well	852

From what has been said of the exposures known, it will be seen that pottery clays are to be looked for in the lower portions of the hills that skirt the Ouachita Valley. The steepness of these hills on the west side of the river gives rise to a great number of natural exposures of the clay beds, but the same beds may confidently be looked for on the east side of the river and in the gentler slopes of that side of the valley, though they are there farther from the stream.

It is noticeable also that good clays are at some places associated with the Tertiary coals or lignites of this region. Thus the lignite, which usually attracts attention more readily than clays, serves to a certain extent as a guide in searching for valuable clays.

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CLAY INDUSTRY.

Notwithstanding the fact that Ouachita County is remarkably well supplied with potter's clays, no clay industry is known to exist in the county at the present time, and the only plant that has existed, and of which information could be had, was a pottery located about 8 miles south of Camden and about 2 miles from Ouachita River, on the farm now belonging to Mr. Thomas Patton (Camden post-office). The clay is said to have come from one of the stratified beds of the hillside. The pottery has not been in operation since the breaking out of the civil war.

PHILLIPS COUNTY.

GENERAL GEOLOGY.

The southern half of Phillips County is covered by the alluvial deposits of Mississippi and White rivers. The northern half is broken by Crowleys Ridge, which has its southern terminus at Helena, on Mississippi River. West of the ridge is a series of much lower ridges, or low swells, which have a general north and south direction. These smaller ridges are broken by streams and intervening depressions.

The elevation of the lowlands in the southern portion of the county is but a few feet above the water in Mississippi River. The elevation of the depot at Helena is 194 feet above sea level. The highest point on the top of the ridge at Helena is 198.9 feet above the zero gage. The elevation of the zero gage is 148.85 feet above sea level. The top of the ridge is therefore 347.75 feet above sea level, and about 150 feet above the lowlands to the west.

The bluffs along the south end of the ridge in the vicinity of Helena give good exposures of Tertiary and Quaternary strata. The loess covers the top and sides of the ridge here as at most places throughout the State. The rearranged product of the loess covers the older underlying strata, which are seen at only a few places.

At the west end of Cherry street in Helena, and along the bluff to the south, there is a bed of iron-stained pebbles, which greatly resemble the pebbles of the Lafayette formation. The top of the pebble bed stands at an elevation of 205 feet. Immediately above the bed of pebbles comes about 10 feet or more of orange-colored loam. Overlying the loam is an apparent soil zone, having a maximum thickness of 10 feet. This is present in many places, but it is at others absent. The remaining part of the bluff is composed of typical calcareous loess, containing numerous land shells.

In places where recent excavations have been made the loess is distinctly stratified. Viewed from a distance it has a general stratified appearance, but when more closely inspected many more faint lines of stratification can be seen.

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At the big spring 2 miles north of Helena, on the east side of the ridge, 80 feet of variegated sands, clays, and lignitic clays are exposed in the deep ravine just north of the spring. The iron-colored pebbles and overlying orange-colored loam, seen at the foot of the bluff on Cherry street in Helena, comes above the 80-foot section of variegated sands and clays at this spring. The top of the bluff is covered with loess.

Along the western edge of Crowleys Ridge in this county there is an apparent terrace from one-half to 3 miles wide. It has a uniform elevation 20 to 30 feet higher than the plain to the west.

A section in a gulley 1½ miles east of Southland shows strata of the character found in the terrace west of the main ridge.

Section of terrace 1½ miles east of Southland.

	Feet.
Stratified dark clayey loam	4
Thin, laminated, argillaceous sand, with small, irregular concretions of iron oxide	4
Yellow argillaceous sand	2

CLAY DEPOSITS AND INDUSTRY.

The principal brick clays of Phillips County are the loess and rearranged loess found on the top and sides and at the foot of Crowleys Ridge. Bricks could be made from the upper loam of the terrace along the west side of the ridge and also from the clays that form the surface of Pine and Hickory ridges. So far, however, the brick industry of the county is limited to the city of Helena.

The plant of the Straub Brick Company is located on the southwest side of the town, at the foot of Crowleys Ridge. The capacity of the plant is 36,000 bricks a day. The bricks are made from the loess, which has been slightly reworked and mixed with the underlying clays. It requires a greater amount of care to make good bricks from this clay than from ordinary clay. The loess is a very fine, silty, calcareous loam, lacking plasticity, and it is very easy to get too much water in the pug mill. It is found to be more profitable to make soft-mud brick in the summer, and dry-pressed brick in the fall and winter.

The bricks are dried in the open air by the pallet and rack system. Most of them are burned in up-draft kilns. Only one down-draft kiln is used.

PIKE COUNTY.

GENERAL GEOLOGY.

The geologic age and character of the deposits in the southern part of Pike County encourage the hope that valuable beds of kaolin exist there. These beds, however, must be sought within the Mesozoic area and not in the region of hard Paleozoic rocks to the north.

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In a general way the northern border of the Mesozoic rocks in Pike County passes from Antoine just north of Wolf Creek post-office, Brocktown, and Murfreesboro, and south of Royalston, passing into Howard County where the county line crosses Muddy Fork of Little River. North of this line it is useless to look for kaolin in commercial quantities in Pike County.[a]

CLAY DEPOSITS.

It has been known for several years that kaolin exists in Pike County, but the only plant of any kind in the county that is engaged in the manufacture of clay products is a small brick plant at Nathan.

Some fine specimens of kaolin were exhibited at the exposition held at Little Rock in the summer of 1887. These specimens were labeled "Pulaski County," but they must have come from the Vaughn Creek beds, in Pike County. At least no such kaolin is known in Pulaski County.[b]

The kaolin beds of Vaughn Creek have been examined by the State Geological Survey at the pits opened in the NW. ¼ SW. ¼ sec. 19, T. 8 S., R. 24 W., near S. D. Hanna's house. The locality is known in the surrounding country as "the chalk bank." Its discovery seems to have been due to the fact that pieces of kaolin were torn out by an uprooted tree. The material has been used to some extent through the country for school chalk.

The kaolin lies in horizontal beds in the tops of the hills that skirt the right bank of Vaughn Creek. These hills are low and are covered with an abundance of waterworn pebbles and cobblestones of Pleistocene age. In the valley of Vaughn Creek, about 75 feet below the summit of the kaolin-bearing ridges, lignites of the Trinity beds (lower Cretaceous) have been found in digging a well at Mr. S. D. Hanna's, in the SE. ¼ NW. ¼ sec. 19, T. 8 S., R. 24 W. The stratigraphic position of the koalin would admit of its belonging either to the lower Cretaceous, the upper Cretaceous, or to the Tertiary. In the absence of other evidence it is therefore impossible to say to which of these horizons it belongs. It is believed that the beds are of Cretaceous age, but this can not be stated as anything more than an opinion based on observations of the topography and stratigraphy of the Cretaceous beds farther west and south.

The accompanying section (fig. 14) is exposed in one of the old prospecting pits dug on the kaolin. It is impossible to say whether this kaolin bed represents the full thickness of the deposit in Pike County. A few other smaller holes have been dug in the immediate vicinity, but as they are all within 100 feet of this one and were dug

[a] The Mesozoic rocks of Pike County are shown on the map of that region accompanying vol. 2 of the report of the Geological Survey of Arkansas for 1888.

[b] In 1890 these specimens, still labeled "Pulaski County," were on exhibition at the rooms of the State Department of Agriculture at Little Rock.

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to strike the same deposits, they throw no light on the nature of the beds except at this one place.

The broken bed *cl* of the section appears to be the remains of a bed of kaolin from which a part of the constituents has been removed by decomposition. The larger fragments, when broken parallel with the bedding, show a great many obscure and small plant impressions, resembling those made by blades of grass. None of the forms seen are recognizable, however. The upper part of the bed marked *ka* in the accompanying section contains a little grit in the form of grains of fine quartz sand. It also shows a great many indistinct and fragmentary impressions of plants. These plant impressions are very small and none of those found are determinable. The lower part of the bed *ka* is pink in color, and contains besides many small white

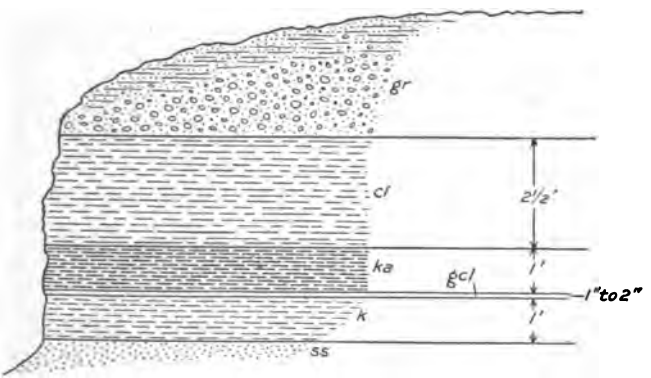

FIG. 14.—Section of kaolin deposits on Vaughn Creek, Pike County. *gr*, Lafayette gravel; *cl*, impure clay; *ka*, pink kaolin with white specks; *gcl*, granular, white streak of clay; *k*, white kaolin, iron-stained joints; *ss*, yellow sand.

spots about the size of a pin's head. These spots are kaolin like the rest, and retain their white color, distinct from that of the rest of the material, even after firing and glazing.

In sec. 19, T. 8 S., R. 24 W., and in sec. 24, T. 8 S., R. 25 W., the following record of the order of the beds is reported by Mr. E. C. Buchanan, of Little Rock:

Section in secs. 19 and 24, T. 8 S., Rs. 24 and 25 W.

	Ft.	In.
Earth and gravel	2	3
Kaolin with sand and red streaks		6
Kaolin and sand	1	6
Kaolin with streaks	1	6
Pinkish sand	1	8

Other pits show the same order, but in some of them the clean kaolin is thicker.

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Mr. Buchanan, after having spent some time in examining the kaolin deposits of Pike County, wrote the following general conclusions regarding them:

The beds are from 3 to 9 feet in thickness and are very variable in color. Shafts only a hundred feet apart exhibit considerable differences in the sections. The following is a typical section as near as such a section is possible:

Typical section in Pike County.

	Feet.
Sand and gravel	3–25
Sand varying in color, but generally reddish or pink, with thin sheets of iron oxide	4
Kaolin, solid, pale yellow to white, with red or yellow streaks	3– 9
Sand	3+

The colors found in one shaft were not always the same as those in an adjacent one. The largest area of kaolin found in one body covered about 10 acres. The greatest depth at which the kaolin was found was 25 feet.

So far as these deposits have been examined they appear to be rather lens-shaped beds of limited distribution. Some of these beds cover only half an acre; others cover an area of 8 or 10 acres. Mr. Buchanan is of the opinion that the entire kaolin area probably does not exceed 350 acres. These lands lie in secs. 19 and 30, T. 8 S., R. 23 W., and in secs. 23, 24, 25, and 26, and probably in secs. 35 and 36, T. 8 S., R. 24 W.

The more massive beds of kaolin contain no evidence of its derivation beyond its sedimentary origin. The kaolin contains, as one might expect, fragments of quartz, but not enough to affect the value of the material for economic purposes. It has a conchoidal fracture, but within the stratum there are no bedding or lamination planes. In the beds above and below it there are evidences that the accompanying strata were deposited in water, a bed of sand underlying and a bed of less pure kaolin overlying it. There can be no doubt, therefore, of the sedimentary origin of the Pike County kaolin.

It is worthy of mention that no exposures of feldspathic rocks are known anywhere in this neighborhood. The nearest large exposure is at Magnet Cove in Hot Spring County, 50 miles distant, but as the Pike County kaolin is Cretaceous it can have no genetic relation to the Magnet Cove rocks, for the latter are probably of post-Cretaceous age; certainly they are not pre-Cretaceous, and could not therefore have supplied the material for this kaolin.

The Pike County kaolin is different in physical characters from any other kaolin thus far found in the State. It is not plastic in its natural condition, but has a hardness of about 1.5 in the mineralogical scale, being easily scratched with the nail. When dry it adheres strongly to the tongue, but it can not absorb enough water to render it plastic, even when left submerged for weeks. In the pit, where it

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is thoroughly soaked with water, it is brittle and breaks with a splintery conchoidal fracture. When dry and rubbed with the hand it takes on a satin-like gloss. Ground to a fine powder and wet, it forms a nonplastic or but partially plastic mass.

A sample of this kaolin that had been left to air dry for several months and then submerged in water cracked to small angular pieces with plainly audible snapping sounds, very much as if it had been a piece of hot glass. Within five minutes the breaking had ceased, and though the kaolin remained in water for several days, it showed no further signs of being affected by it.

The fact that this kaolin does not soften in water like clay is a disadvantage, for it would need to be ground and washed before it could be used in the manufacture of fine pottery. A sample of it has been put to a practical test by being fired and glazed in one of the New Jersey potteries. It stood this test in a very satisfactory manner.

Below are given analyses of both the upper pink and the lower white kaolin of the section given on page 149. The locality is in the NW. ¼ SW. ¼ sec. 19, T. 8 S., R. 24 W. These analyses may be compared with those of well-known kaolins in the table on pages 236–237.

Analyses of kaolins from Vaughn Creek.

[Dr. T. C. Van Nuys, analyst.]

	Upper bed.	Lower bed.
Silica (SiO_2)	48.87	47.39
Alumina (Al_2O_3)	36.51	34.67
Iron (ferric) oxide (Fe_2O_3)	.98	2.31
Lime (CaO)	.19	.32
Magnesia (MgO)	.25	Trace.
Potash (K_2O)	.....	.20
Soda (Na_2O)	.....	.39
Water	13.29	13.89
	100.11	97.17
Water at 110°–115° C	.....	1.00

At the pit from which the sample of the lower bed was taken the kaolin is much fractured, and iron-charged waters have infiltrated along these fracture lines and stained them a deep brown color, though the material still holds together compactly. When a mass removed from the bed is struck hard, it breaks along these fractures. The iron stain seriously injures the kaolin, probably rendering it worthless for fine ware. It is evident, however, that the iron has been leached from the waterworn gravels, sands, and clays that cover the surface of the ground and has been redeposited in the only part of the kaolin it could easily penetrate—that is, along these crevices. If, therefore, kaolin available for the manufacture of the finer grades of porcelain exists in commercial quantities in the neighborhood of the Vaughn Creek pits, it should be looked for at places where it will have a covering thick enough to protect it from infiltration of iron-charged waters from the surface.

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The analyses of this kaolin show that except for the stains referred to above it is sufficiently pure for the manufacture of fine porcelain ware. It seems to be well adapted also for paper finishing. It also has high refractory properties, and in case it can not be found free from the impurities that would injure it as a china clay, it is still available for the manufacture of a high grade of fireproof articles.

Prospecting for kaolin that lies in horizontally stratified beds, as do these of Pike County, is a very simple matter and will not be expensive unless one happens upon thick deposits of the Pleistocene waterworn material that covers the surface of the ground. The accompanying diagram (fig. 15) is intended to show the method of occurrence of the kaolin with reference to the waterworn gravels of that region.

A vertical section cut through these beds would show that they have some such relations as those indicated in the diagram. The kaolin lies in a horizontal bed, *ka*, and the sands, *ss*, clays, *cl*, etc., associated with it, are also horizontally bedded. These beds have been worn away from above and the great body of kaolin originally deposited has been removed. What remains is fragmentary and,

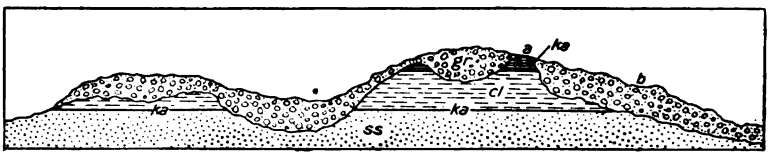

FIG. 15.—Section of kaolin beds in Pike County.

in the vicinity of the Vaughn Creek pits, at least, lies in the hilltops, but over the worn surface gravel beds, *gr*, have been spread out, covering the greater part of the surrounding country. This gravel varies greatly in thickness. At some places it is almost entirely wanting or is represented by only a few pebbles, while at others it has a thickness of 30 feet or more. It is at many places impossible to foresee the thickness of this gravel covering, for, as will be realized from the diagram, the thickness at *a* would give a miner no clue whatever to the thickness of the same deposit at *b*, and vice versa.

The horizontality of the kaolin beds makes prospecting for them simple and cheap. It is only necessary to ascertain the elevation on the hillside at which the bed is to be exposed, judging from the elevation at which it occurs at known localities, and then to dig a trench up and down the face of the hill so as to crosscut the bed. This trench should pass entirely through the waterworn gravels and uncover the underlying beds. If the kaolin bed were perfectly horizontal such a trench would not be necessary, for a pit could be opened directly on the bed, but its position varies somewhat, and this variation makes the trench necessary.

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It will be seen from the foregoing that whether or not considerable quantities of kaolin are to be expected in the region west of Vaughn Creek in Pike County depends on the topography of the country. If the hills are all lower than the point at which the outcrop is found, near Mr. Hanna's, the kaolin has all been washed away. If the hills are higher and their height is not due to the great thickness of the gravel bed, the kaolin may reasonably be expected to outcrop on the hillsides. In broad and flat-topped hills, with kaolin outcropping around the margins, prospecting may be done by boring with testing augers on the hilltop. If the boring is in a depression it will not be necessary to bore through so great a thickness.

There is a very widespread and a very erroneous impression among a certain class of miners that mineral deposits grow thicker and better as one goes deeper. In the case of this kaolin, other things remaining the same, the material will improve as the cover thickens, but this is simply because the thicker cover prevents the infiltration of iron into the kaolin. Whether the beds thicken or not can not be predicted, but in view of the sedimentary origin of the deposit it is reasonable to suppose that they will not vary greatly in thickness.

In the SW. ¼ NE. ¼ sec. 24, T. 9 S., R. 24 W., a bed of kaolin is said to have been discovered in digging a grave about the year 1874. This point is said to be on the top of a sandy hill or bench about 30 feet above the "bottoms" of Little Missouri River.

POINSETT COUNTY.

GENERAL GEOLOGY.

The topography of Poinsett County is very similar to that of Cross County on the south and Craighead on the north. The eastern half of the county is a low, flat country, which is traversed by St. Francis River. A large area in the northeastern part is covered by shallow lakes, which were caused by the general sinking of the land during the earthquake period of 1811–12. Crowleys Ridge extends across the county in a north-south direction just west of the center. The country west of the ridge is a flat slash land sloping to the south and west. The elevations along the St. Louis, Iron Mountain and Southwestern Railway, in the western part of the county, are from 7 to 24 feet higher than corresponding points in the same latitude along the St. Louis and San Francisco Railroad in the eastern part of the county.

The Tertiary sands and clays outcrop in deep ravines and in roads along the sides of Crowleys Ridge, in the vicinity of Harrisburg, and doubtless at other places on the east side of the ridge. The top of the ridge at Harrisburg is 107 feet (barometric reading) above the

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elevation of the town at the foot of the ridge. The following is a section of the hill along the road leading east from the town:

Section of Crowleys Ridge at Harrisburg.

	Feet.
Yellow clay (Columbia) on top of ridge	30
Stratified sand, variegated in color, interbedded with gray joint plastic clay	65
Unexposed detritus to foot of hill	12

A record of one of the wells in the town at the foot of the ridge gives the following section:

Section of well in town of Harrisburg.

	Feet.
Red to yellow clay, with some gravel	40
Blue gumbo clay free from sand, with small vein of water on top	25
Very fine red dry sand, which caves badly	40
Dark-blue or slate-colored sandy clay, containing small fragments of leaves, shells, and rotten wood; gives bad odor to water	50
Blue sand, water bearing	30

CLAY DEPOSITS.

The surface clay, which is 40 to 50 feet thick at foot of the ridge at Harrisburg, is only about 10 feet thick at L'Anguille River, 4 miles west of town. It changes from a reddish yellow at the foot of the ridge to white at L'Anguille River. In places it forms buckshot soil.

The surface yellow clay on the top and sides of the ridge, and also the surface clay in the lowlands as far west of L'Anguille River, are well suited to the manufacture of common wet or stiff-mud and dry-pressed bricks. The blue Tertiary clay that outcrops well up on the side of the ridge would, with proper manipulation, doubtless make an excellent face brick. The following analyses are made from brick clay at Harrisburg, Poinsett County:

Analysis of brick earth from the surface, Harrisburg.

[Dried at 110°–115° C. Brackett & Smith, analysts.]

Silica (SiO_2)	81.79
Alumina (Al_2O_3)	9.37
Iron oxide (Fe_2O_3)	4.03
Manganese (MnO)	Trace.
Lime (CaO)	.31
Magnesia (MgO)	.38
Potash (K_2O) (by difference)	.86
Loss on ignition	3.26
	100.00
Air-dried sand in air-dried clay	30.92

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Brick earth at depth of 4 feet, Harrisburg.

[Dried at 110°-115° C. Brackett & Smith, analysts.]

Silica (SiO_2)	81.37
Alumina (Al_2O_3)	8.52
Iron (Fe_2O_3)	2.88
Manganese (MnO)	1.01
Lime (CaO)	.44
Magnesia (MgO)	.50
Potash (K_2O) and Soda (Na_2O) (by difference)	2.40
Loss on ignition	2.88
	100.00
Air-dried sand in air-dried clay	28.08

Analysis of clay from an old clay pit at Harrisburg in sec. 25, T. 11 N., R. 3 E.

[Sample dried at 110°-115° C. R. N. Brackett, analyst.]

Silica (SiO_2) (free and combined)	75.93
Alumina (Al_2O_3)	11.05
Iron oxide (Fe_2O_3)	6.10
Lime (CaO)	.67
Magnesia (MgO)	.76
Potash (K_2O)	.72
Soda (Na_2O)	63
Phosphoric acid (P_2O_5)	.20
Loss on ignition	4.56
	100.62
Air-dried sand	37.62

The large amount of iron oxide and small amount of lime will give a deep red colored product.

The following analysis was made from the loess brick clay which came from the top of Crowleys Ridge, a short distance north of Spencer Creek, in Poinsett County:

Analysis of loess from Crowleys Ridge north of Spencer Creek.

[Dried at 110°-115° C. Brackett & Smith, analysts.]

Silica (SiO_2)	85.83
Alumina (Al_2O_3)	7.50
Ferric oxide (Fe_2O_3)	2.66
Manganese (MnO)	Trace.
Lime (CaO)	.32
Magnesia (MgO)	.35
Alkalies (by difference)	1.16
Loss on ignition	2.18
	100.00
Air-dried sand in air-dried soil	64.80

There is a striking similarity in the appearance of surface clay on top of Crowleys Ridge at Spencer Creek and the yellow clay that

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occupies the surface of the country between Crowleys Ridge and L'Anguille River, west of Harrisburg. The similarity is made more evident by comparing the analysis of the loess above given and the one following.

Analysis of upper layer of the "buckshot land" from Harrisburg, sec. 25, T. 11 N., R. 3 E.

[R. N. Brackett, analyst.]

Silica (SiO_2)	87.50
Alumina (Al_2O_3)	6.10
Iron oxide (Fe_2O_3)	2.69
Lime (CaO)	.63
Magnesia (MgO)	.36
Potash (K_2O)	.38
Soda (Na_2O)	.65
Phosphoric acid (P_2O_5)	.13
Loss on ignition	1.95
	100.49
Air-dried sand	77.48

CLAY INDUSTRY.

Common wet-mud bricks are made by W. P. Lancaster and J. B. Huey at Harrisburg. The product is made from the reworked Columbia or loess, which is 8 feet thick. The clay is tempered in soak pits, molded by horsepower machinery, dried on pallet and racks, and burned in up-draft scove kilns. The plant has a capacity of 8,000 bricks a day. Five to six days are required for drying, and ten to twelve days for burning. The green bricks can not be taken from the molds and placed in the sun immediately.

POPE COUNTY.

GENERAL GEOLOGY.

A part of Pope County and all of the other counties farther west along Arkansas River lie within the area of the Carboniferous coal-bearing rocks. The coal-bearing rocks in these counties do not differ greatly from those in Conway, Faulkner, White, and Pulaski counties farther east, where coal is not present, but the presence of the coal beds adds another factor that must be taken into account in dealing with the clays and clay industries.

The coal-bearing rocks in Pope County and the counties to the west are folded like those of the region to the east and southeast; in places these folds are sharp, in others they are gentle. The clay shales are interbedded with sandstones and with coal. As a rule they are compact where they lie under other beds, but where they have been exposed for a long time to the weather they become soft and plastic. In color they vary from almost black through various shades of gray,

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and weathering, become gray, yellow, or red. Among these clay shales that are associated with the coal seams the refractory clays are found.

In Pope County the sandstones usually cap hills or form ridges, just as they do in the counties farther east and south, while the shales as a rule underlie the valleys.

The sandstone ledge that forms the abrupt edge of Carrion Crow Mountain from Atkins to Galla Creek is widespread in western Arkansas, and was called by the Arkansas Geological Survey the Hartshorne sandstone, from Norristown Ridge, southwest of Russellville. This bed passes around the north side of Carrion Crow Mountain and forms the low hills from 2 to 4 miles north of Russellville. It also forms the rim of Tucker Mountain, from 4 to 8 miles north of Russellville, and crosses Illinois Creek to form the escarpments of Illinois Ridge, west of that stream. South of Tucker Mountain the rocks are bent into a trough or synclinal fold, and the Hartshorne sandstone bed is tipped up on edge to form Ouita Ridge.

The same bed of sandstone, after passing southward beneath the Ouita coal basin, comes to the surface again to form Norristown Mountain and Dardanelle Ridge and also Reeds Ridge, northeast of the ferry at Dardanelle. Special attention is called to this particular bed of sandstone because it furnishes the key to the structural geology of Pope County.

No workable coal is known in Pope County below the Hartshorne sandstone, though there is a bed 18 inches thick below it in Carrion Crow Mountain. The coal of the Ouita basin and that of the Shinn mines, south of Russellville, overlie it. If the Ouita bed existed about Carrion Crow Mountain it would be on top of the mountain, not on its flank. The Ouita coal bed lies south of Ouita Ridge because the sandstone dips southward, forming a basin or trough whose southern edge is Dardanelle Ridge. The Shinn mines lie north of Reeds Ridge because the sandstone of that ridge dips northward.

Important beds of shale and fire clay lie both above and below the Norristown sandstone. The shale above the Hartshorne sandstone has been called the Spadra shale, because it occurs typically at the Spadra coal mines. The Ouita coal bed at these mines and the same bed at the Shinn mines is in the Spadra shale, near its base. The Spadra shale is mostly a clay shale, though it is usually more sandy toward the top, and varies in thickness from 100 to 500 feet. The shales on the top of Carrion Crow Mountain belong to this set of beds. They everywhere accompany the Ouita coal bed and dip as the coal dips. Starting at Illinois Creek in sec. 29, T. 8 N., R. 20 W., these shales cover the whole area lying between Ouita Ridge and Dardanelle Ridge and west of Norristown Mountain. Below the Ouita coal bed—

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that is, between the coal and the Hartshorne sandstone—lie 3 to 5 feet of fire clay and shale.

Below the Hartshorne sandstone there is a thick deposit of shale. The relations of this bed to the Hartshorne sandstone are well shown in the following section of Carrion Crow Mountain just north of Atkins:

Section of Carrion Crow Mountain.

	Ft.	in.
Hartshorne sandstone	45–180	
Shale	180–190	
Coal		18
Shale	160–200	

This shale can be traced throughout Pope County, in which it everywhere underlies the Hartshorne sandstone. It lies along the upper flank of Carrion Crow Mountain and of Tucker Mountain. Where Mill Creek cuts through Ouita Ridge it is well exposed below the Hartshorne sandstone to a thickness of about 300 feet.

This shale is underlain by a sandstone, and this in turn by still another shale. This last shale underlies the town of Russellville. The overlying sandstone does not seem to exist in the vicinity of Russellville, or if it does it is thin and unimportant. The great thickness of shales between the town of Russellville and Norristown Mountain therefore extends up to the lap of the Atoka formation. These shales probably have a thickness of 200 to 400 feet in the vicinity of Russellville. They form the lower flank of Carrion Crow Mountain, and the thin bed of coal there exposed is in these shales. They are well exposed on the Russellville-Dover road just south of Baker Creek and also along the west side of the same road along the base of Tucker Mountain. Buck Mountain, in T. 9 N., R. 19 W., is made of this shale, and in that mountain it has a measured thickness of 375 feet. Iron Ore Mountain, in T. 8 N., R. 18 W., is also made up principally of this shale.

CLAY DEPOSITS.

No analyses or tests have yet been made of the clay shales of Pope County. Where valuable shales are closely associated with workable coal beds, or even with coal beds which alone are not workable, it sometimes becomes economically possible to mine the coal and some of the shale together, with a view to utilizing the latter. There is no doubt that there are in Pope County enormous quantities of shales available for the manufacture of paving bricks, sewer pipe, and fire-clay goods. The occurrence of such raw materials in connection with abundant, excellent, and cheap coal and the cheap and convenient transportation afforded by Arkansas River afford highly favorable conditions for the building up of important manufacturing industries.

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Material suitable for brickmaking covers a large area around Atkins, extending from W. H. Murphy's old brickyard at the base of Carrion Crow Mountain, in the SW. ¼ SE. ¼ sec. 20, T. 7 N., R. 18 W., eastward over several sections. This material varies much in depth, while at some places its continuity is broken by small gravel ridges.

On the line between the SW. ¼ NW. ¼ sec. 4 and the SE. ¼ NE. ¼ sec. 5, T. 7 N., R. 18 W., and over the greater portion of these lots, there is a fine light-colored clay about 4 feet thick. It is almost white in color, although there are spots of brown here and there toward the eastern side of the area.

Analysis of clay from sec. 5, T. 7 N., R. 18 W.

[Brackett & Smith, analysts.]

Silica (SiO_2)	90.49
Alumina (Al_2O_3)	5.22
Ferric oxide (Fe_2O_3)	1.38
Lime (CaO), Magnesia (MgO), Potash (K_2O), Soda (Na_2O)	Trace.
Loss on ignition	3.12
	100.21
Fine sand specimen	30.53
Water at 110°–115° C	1.60

In the NE. ¼ SE. ¼ sec. 26, T. 7 N., R. 19 W., there is an area of about 10 acres containing a soft brown and blue argillaceous shale, showing an exposure of 2 feet in the side of a creek. These shales are very soft and can readily be worked into a clay for the manufacture of fire-clay goods.

The clays around Russellville vary in color from a yellowish brown to an ashen white, according to the position of the material in the bed. In general the surface clay is darker than the underlying material. This difference in color varies in different places. In secs. 8 and 9, T. 7 N., R. 20 W., the upper clay is yellowish brown and varies in depth from 1 foot on the southern side of these sections to 3 feet along the bank of the creek that flows northeastward past Russellville. The lower division of this clay as exposed in the bank of the creek is pale yellow, almost white, and contains a great quantity of nodules of iron.

This buckshot clay rests immediately on the dark-blue argillaceous shales of the coal-bearing rocks and varies in thickness from 1 foot to 5 or 6 feet. On the slight ridge immediately south of Russellville, in the NW. ¼ sec. 9, it is not more than 1 foot thick, but in the land along the creek and between the Little Rock and Fort Smith Railway and the Dardanelle Railway it shows a thickness of 6 feet.

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A short distance north of Russellville the thickness is reduced to 3 or 4 feet.

In area this clay covers secs. 4, 5, and 9 and the greater portion of sec. 8, T. 7 N., R. 20 W. It is also scattered through secs. 10, 11, 12, 13, and 14 of the same township and range. At Galla Creek station on the Little Rock and Fort Smith Railway, in sec. 19, T. 7 N., R. 19 W., it appears as a dark-yellow clay.

CLAY INDUSTRY.

Common bricks are made by the Mena Brick Company at its plant 2 miles southwest of Mena from a thin bed of clay overlying the shale. The clay is partly residual, since it contains many fragments of shale. The clay is first run through a Success crusher, then through a pug mill of the same make, and finally through a stiff-mud machine. About 4,000 bricks are made daily. The machine is run by a 40-horsepower engine. Usually 10 men are required to run the plant—two men in the pit, two feeders (one to temper the clay), one sander, two off-bearers, and two truckers. About one-half of the time is employed in molding and one-half in burning.

Another plant belonging to the same company is located 1½ miles from Mena, but it will probably be sold and removed to De Queen.

There is a brick plant at Russellville, known as the Russellville brick works, but nothing further is known concerning it.

There is a small brick plant at Atkins, with a capacity of 5,000 to 6,000 a day. The bricks are made by hand and burned in common scove kilns. It requires from two to five days for drying and ten to twelve days for burning. The bricks are made from the residual clay of the Paleozoic rocks. The size of the molds is 9 by 4 by 2½ inches; when burned the bricks measure 8½ by 3⅝ by 2¼ inches.

PRAIRIE COUNTY.

GENERAL GEOLOGY.

The southern half of Prairie County lying west of White River is level prairie land. The part that lies north of township 2, with the exception of a small area around Desarc, is chiefly wooded "slash land." The soil of the country east of White River is entirely alluvial, and the surface stands but a few feet above the low-water mark in White River.

Throughout the county White River has formed a bluff of varying height along its west bank. At Devall Bluff the level of the prairie land west of the river is 25 to 40 feet higher than the high-water mark in the river. The elevation of the depot at Devall Bluff is 186 feet, or about 7 feet lower than the depot at Helena.

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The strata west of White River are of late Quaternary age. The surface material of the prairie land is a reddish clay loam or gray buckshot clay. On the higher ridges, where water does not stand for any great period, the surface clay and subsoil is a red clay very similar to the second-bottom or terrace clays along the west side of Crowleys Ridge in Lee and Phillips counties. In the low slash lands, which are covered with water for several months during the year, the surface clay was doubtless originally the same kind of material as that on the prairie lands. But the iron oxide of the prairie soils has been segregated into small limonitic concretions, which have received the local name of buckshot. The soils of the slash lands are therefore more or less leached and have a white to grayish color.

The character of the strata found in wells and in the bluff at Devall Bluff is shown in the following sections:

Section of bluff at Devall Bluff.

	Feet.
Yellow clay loam, in places buckshoty	10
Stratified reddish sand, very fine grained	8
Red plastic clay to bottom of gully	3

The yellow surface clay is used here for making brick. In the prairie land at Tollville, 6 miles southwest of Devall Bluff, the following well record was obtained:

Record of well at Tollville.

	Feet.
Yellow clay	3
Hardpan, gray clay	10
Reddish clay grading into a gray sand	20
Very fine quicksand, supplying water	10
Red clay	50
Soft gray clay	4
Gravel and sand; source of water	(?)

Over much of the prairie region there are numerous small spheroidal mounds which are rarely more than 2 feet high and 50 feet across the base. They are different from the larger mounds of undoubted human origin. The origin of these mounds has been a great mystery to all those who have studied them. By some they are thought to have been built by Indians, others have considered them to have been built by ants, and still others have attributed their origin to natural agencies, as winds and waves.

CLAY INDUSTRY.

Common building bricks are made at Devall Bluff. The Devall Bluff Brick and Tile Company manufactures a stiff-mud side-cut brick. The bricks are made from the red surface clay. They will check when

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dried too rapidly, and therefore have to be dried in covered sheds. The bricks are burned with wood in up-draft kilns. The capacity is 5,000 bricks a day. The output of bricks is largely governed by the local demand. They can not compete with bricks made at Little Rock, where convict labor is used in the yards.

PULASKI COUNTY.

GENERAL GEOLOGY.

The northwestern edge of the Tertiary beds crosses Pulaski County 2 or 3 miles northwest of the Iron Mountain Railway and keeps about parallel with it from Little Rock toward the southwest. Northwest of this Tertiary margin the rocks of the county are much folded, and are either Silurian or Carboniferous, while toward the south and east they are nearly horizontal and are Tertiary and Quaternary. The granites or syenites of the Fourche Mountain region are of earlier age than the Tertiary sediments to the south and east. They furnish the kaolins of Pulaski County, and have also probably been the source of much of the valuable clays of this and of adjoining counties.

CLAY DEPOSITS.

DISTRIBUTION.

But little is known of the details of the distribution of the clays in the extreme southern part of the county. South of the Fourche Mountain region the land is low and flat, and it is to be expected that ordinary brick clays are spread over that part of the county in great abundance. In the immediate vicinity of Fourche Mountain there is much pisolitic kaolin.

Pulaski County clays are best exhibited in the southwestern part of the city of Little Rock, and extend thence southwestward to the town of Alexander, on the Iron Mountain Railway and on the county line. Anywhere along this Tertiary margin a section drawn from the Paleozoic region on the northwest toward the southeast would show approximately the same geologic structure.

FOURCHE MOUNTAIN DISTRICT.

The feldspathic rocks of Pulaski County cover a total area of 8 or 9 square miles, all in the vicinity of Fourche Mountain, near Little Rock. White clays are found over this same area at various places. They also occur in the township next west, in the vicinity of Mabelvale, where no feldspathic rocks are known at the surface. The surface exposures are in secs. 5 and 9, T. 1 S., R. 12 W., and secs. 2, 10, 11, and 12, T. 1 S., R. 13 W.; and clays have also been found in wells in secs. 25, 26, 35, and 36, T. 1 N., R. 12 W.

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In the NE. ¼ and the NE. ¼ NW. ¼ sec. 9, T. 1 S., R. 12 W., the exposures of clay occur on the middle Pine Bluff road about a quarter of a mile south of the end of the turnpike. It is exposed along both sides of the road for a distance of about 300 feet, and again in the road leading from the main road to D. Rausch's house for about 250 feet. At these exposures the clay where it is first seen has a dark pearl color and comes out in angular blocks that are somewhat stained with iron. Nothing is known of the depth or extent of this material, but it is probable that it will be found clearer of iron stain at no great distance below the surface, for the iron that coats many of the blocks has been washed into the crevices from the overlying surface sands. Small surface fragments seem to show that it extends to the middle of sec. 8, the section next west of that in which these exposures occur, and also into sec. 10 on the east. In the NW. ¼ NW. ¼ sec. 8 it is said to have been cut in a well at a depth of 14 feet. About 100 feet north of D. Rausch's house clay mingled with syenite bowlders is exposed at the surface. A light-gray clay is also reported from the W. ½ NW. ¼ sec. 15, T. 1 S., R. 12 W., but the locality has not been examined.

A well in the NW. ¼ NE. ¼ sec. 2 of this township is said to have penetrated white clay at a depth of 27 feet. A small exposure is also reported at the corner between secs. 3, 4, 9, and 10. Mr. E. C. Buchanan reports an outcrop in the SW. ¼ SE. ¼ sec. 3, T. 2 S., R. 13 W., similar to that found in sec. 9. Samples of this kaolin from the road near the middle of sec. 9 were analyzed and subjected to various practical tests in order to determine its availability as a china clay.

Analysis of Pulaski County kaolinite from sec. 9, T. 1 S., R. 12 W.

Silica (SiO_2)	46.27
Alumina (Al_2O_3)	38.57
Iron (ferric) oxide (Fe_2O_3)	1.36
Lime (CaO)	.34
Magnesia (MgO)	.25
Potash (K_2O)	.23
Soda (Na_2O)	.37
Water	13.61
	101.00
Water at 110°–115° C	1.57

It will be seen that the percentage of iron in this clay is rather high. Samples were tested by practical potters at Trenton, N. J., with the following results: The body of the crude clay burns a beautiful white, but a great number of rusty brown specks are scattered over this white ground, the largest of them one-sixteenth of an inch in diameter. This clay cracks in firing, but not enough to prevent its use for fine pottery if it were available in other respects. The iron in this clay

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seemed at first to offer a serious impediment to its availability, but some of the material was ground and thoroughly mixed and made into a paste and tested by firing. The samples came from the furnace in a much better condition than the crude clay—that is, it was free from the rusty brown specks—but the iron had only been evenly distributed through the mass, and the result was that the sample came out with an ivory color instead of pure white. It takes the glaze well and is regarded by the potters as available for such wares as do not require a pure white body.

The clay at this locality (middle of sec. 9) as it comes from the ground is not plastic, nor is it soft enough to admit of its being taken out with a spade or shovel, but it is so hard as to require crushing. It comes out in angular blocks of various sizes; it is readily cut with a pick and has an earthy fracture. It is at first of a dark-pearl color, but upon drying takes on a cream color. The blocks from near the surface are covered with more or less iron stain, but this coating is readily removed, and it probably does not extend to any considerable depth.

Wells dug in secs. 25 and 26 and 35 and 36, T. 1 N., R. 12 W., disclose the existence of clay at various depths. At a small stream in the orchard near William Tarpley's house, in the NW. ¼ NW. ¼ sec. 36, a well 16 feet deep shows the following section:

Section in well in sec. 36, T. 1 N., R. 12 W.

	Ft.	in.
Gravel and sand	5	
Iron ore		2½
Joint clay	3	
Kaolinite	8	
Syenite (?) at bottom.		
	16	2½

In another well, 18 feet deep, on the top of the hill north of the well just mentioned, in the same orchard and nearer the house, no clay was found. The following is a section of this well:

Section in well near William Tarpley's house, in sec. 36, T. 1 N., R. 12 W.

	Feet.
Waterworn pebbles	6
Joint clay	8
Sandstone	4
Syenite at bottom.	
	18

These two wells are not more than 200 feet apart and the difference of elevation between their mouths is about 30 feet. It is evident that these clay beds are irregular in shape and thickness.

The clay found in Mr. Tarpley's well is very soft and almost milk white in color. Small patches of iron stain appear in places.

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The following is an analysis of this clay:[a]

Analysis of clay from Tarpley's well.

Silica (SiO_2)	45.28
Alumina (Al_2O_3)	37.39
Iron (ferric) oxide (Fe_2O_3)	1.71
Lime (CaO)	1.83
Magnesia (MgO)	.29
Phosphoric acid (P_2O_5)	.06
Water, after having been dried at 110° C	13.49
	100.05

In the NE. ¼ SE. ¼ sec. 35, T. 1 N., R. 12 W., on the farm of J. M. Dickinson, a well 48 feet deep gives the following section:

Section of well in sec. 35, T. 1 N., R. 12 W.

Thin gravel at top.	Feet.
Red clay	16
White clay	1
Yellow pisolite (bauxite ?)	6
White clay	25
	48

Water was obtained before the last body of clay was passed through. Its actual thickness in this well is, therefore, not known.

In Mr. Dickinson's yard, about 100 feet east of this well, another well shows clay at 23 feet. In the latter well the yellow pisolite appears at 16 feet and the 1-foot band of white clay seen in the 48-foot well is absent. The following is a section of this well:

Section in well at house of J. M. Dickinson.

Thin gravel at top.	Feet.
Red clay	16
Yellow pisolite (bauxite ?)	6
Kaolinite in bottom	1
	23

The difference in elevation of the mouths of these two wells is not more than 4 feet. The specimens of clay obtained from the 48-foot well are of grayish-white color and show iron stains on the surface. There are signs of clay at the fork of the roads in the NE. ¼ sec. 26, but no systematic search has been made to ascertain whether it occurs in quantity or of a quality that will render it valuable.

In the neighborhood of Sweet Home station, in sec. 25, T. 1 N., R. 12 W., several wells are said to have passed into a white pipe clay, probably the white clay found in the village half a mile west of the station.

[a] This analysis was made by Mr. W. R. Cravens under the direction of Dr. T. C. Van Nuys, professor of chemistry at the University of Indiana.

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Those who may seek for clay in the Fourche Mountain district should bear in mind that it is not likely to be found on the hilltops, but rather in the lower grounds, where the rocks are kept constantly saturated with the acid waters by which decomposition is produced. It is surmised that places favorable to the formation of clay beds may be found in the northern part of sec. 3, T. 1 S., R. 12 W.

It should be added that at several places the lower portions of the bauxite beds of Pulaski County grade into clays.

MABELVALE DISTRICT.

The Mabelvale district lies about halfway between the Fourche Mountain district, south of Little Rock, and the Saline County district. No feldspathic rocks have been observed in the immediate neighborhood of Mabelvale, but a band connecting the Fourche Mountain and the Saline County areas would embrace Mabelvale. This fact and the existence of bauxite seem to suggest the probability that syenites exist not far beneath the surface in the vicinity of Mabelvale. The clays in this district are all more or less pisolitic, and are believed to be simply the kaolin varieties of bauxite. Their chemical composition, however, seems to suggest the possibility that some of them may be available as china clays.

On the middle of the east side of the NW. ¼ sec. 10, T. 1 S., R. 13 W., about 150 yards south of the west end of the railway siding at Mabelvale station, on the St. Louis, Iron Mountain and Southern Railway, there is a deposit of bauxite which merges into pisolitic clay, the two covering about 25 acres. The material outcrops at many points, but it is concealed for the most part by a thin covering of sand and pebbles and nodules of sandy limonite. The covering becomes gradually more abundant toward the higher ground and thins out on the margins of the knolls. But little is known of the actual area covered by the clay. A well said to have been dug 92 feet deep at the house of J. W. Hopkins, within 300 feet of the western outcrop, is reported to have penetrated 8 feet of soil and then "soapstone," or gray clay, all the rest of the way.

The following analysis shows the character of the clay from the Mabelvale locality:

Analysis of pisolitic clay from SE. ¼ NW. ¼ sec. 10, T. 1 S., R. 13 W.

[Brackett & Smith, analysts.]

Silica (SiO_2)	45.20
Alumina (Al_2O_3)	37.60
Iron (ferric) oxide (Fe_2O_3)	3.00
Lime (CaO)	.89
Magnesia (MgO)	Trace.

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Potash (K_2O)	0.06
Soda (Na_2O)	.69
Water (loss on ignition)	13.54
	100.98
Very fine sand	.25
Water at 110°–115° C	.62

This contains a large amount of iron, but it is probable that material found at greater depth will contain less iron than that nearer the surface.

White pisolitic clay is also exposed in the NE. ¼ NE. ¼ sec. 10, less than half a mile southeast of the railway station. This material crops out in the road. Just south of the road, about 15 paces from it, a well was at one time put down, and the following is reported as the section passed through:

Section in well in sec. 10, T. 1 S., R. 13 W.

	Feet.
Yellow clay soil (dug)	3
Pisolitic clay (dug)	14
Pisolitic clay (bored)	14
	31

The clay was not penetrated at this depth, so that its total thickness is not known. This well record is also said to bear out the suggestion that the clay becomes softer and cleaner as the depth increases. The extent of this deposit is not known, but it probably does not exceed 5 acres.

The analysis given below shows that this material contains less iron than the sample taken near Mr. Hopkins's place, in the same section.

Analysis of pisolitic clay, NE. ¼ NE. ¼ sec. 10, T. 1 S., R. 13 W.

Silica (SiO_2)	48.05
Alumina (Al_2O_3)	38.92
Iron (ferric) oxide (Fe_2O_3)	1.19
Lime (CaO)	.58
Magnesia (MgO)	.45
Potash (K_2O)	.18
Soda (Na_2O)	.28
Water (loss on ignition)	10.86
	100.51
Water lost at 110°–115° C	.46

Another deposit, which shows in the form of bauxite at the surface, but which will probably be found to contain a pisolitic clay a short distance below the surface, occurs in the SW. ¼ SE. ¼ sec. 2, T. 1 S., R. 13 W., and nearly or quite on the line between secs. 2 and 11, the greater part of it lying between the forks of the road at this point. The total area covered by this deposit probably does not

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exceed 4 acres. Where this material is exposed at the surface it is pisolitic, hard, and iron stained. A well sunk in it showed that it resembles the other deposits of this region in being softer and whiter below the surface. The surface fragments have been used somewhat for building chimneys and for setting boilers, to which purposes its fireproof qualities make it well adapted.

In the SE. ¼ SW. ¼ sec. 12, T. 1 S., R. 13 W., loose fragments of pisolitic clay are scattered over the surface and a few small exposures are visible. There are no means, however, of knowing the nature or extent of this deposit, but if this kind of clay proves to be valuable it would be worth while to prospect at this place.

The following is the record of a well dug at Mabelvale, in the NE. ¼ NE. ¼ sec. 10, T. 1 S., R. 13 W., in the yard of Mr. A. W. Norris:

Section in well at Mabelvale.

	Feet.
Yellow surface clay	5
Reddish clay	1
Dove-colored joint clay or "soapstone" clay with occasional "iron pots" and some manganese streaks	16
Ferruginous sandstone	2
Black clay in the bottom.	
	24

The dove-colored clay of this section is soft and unctuous, and is popularly known as "soapstone." The "iron pots" (hollow masses of iron ore, some a foot in diameter, resembling waterworn cobbles) found in this bed are so large and so sparsely scattered through the bed that they can not seriously interfere with the use of the clay.

This clay bed is probably widespread in the neighborhood of Mabelvale, lying at or near the surface. It was passed through in digging the well in the public square at Mabelvale. The section of this well given below is a sort of average made up from several reports, which disagree somewhat in minor details, but not in any essential features.

Section of well in public square at Mabelvale.

	Ft.	in.
Yellow surface clay	5	
"Soapstone clay"	10–15	
Ferruginous sandstone	2	
Black clay	10	
Limestone		8
Black clay	10	

The following analyses give the composition of the "soapstone" clay bed. No. 1 is an average sample from the well at Mr. Norris's house. The analysis was made by the Geological Survey of Arkansas. No. 2 was sent for analysis by McCarthy & Joyce, of Little Rock, to

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Prof. W. B. Potter, of St. Louis. A copy of the analysis was kindly furnished by Mr. Norris.

Analyses of "soapstone" clay, from well of A. W. Norris, NW. ¼ NE. ¼ sec. 10, T. 1 S., R. 13 W.

	1.	2.
Silica (SiO_2)	65.27	60.79
Alumina (Al_2O_3)	18.75	19.73
Oxide of iron (Fe_2O_3)	7.34	5.94
Lime (CaO)	.81	.37
Magnesia (MgO)	1.26	.72
Potash (K_2O)	1.10	1.93
Soda (Na_2O)	.81	
Loss on ignition (H_2O)	6.88	10.77
	100.22	100.25
Water lost at 110°–115° C	9.46	.....

No sand.

This clay is convenient to transportation and well adapted to the manufacture of paving bricks, sewer pipes, and probably fire bricks. The beds are horizontal, and at points where the surface is somewhat lower than at Mr. Norris's can be reached without much stripping.

The following sections of wells in the vicinity of Mabelvale, although evidently imperfect and unsatisfactory, are given for what they are worth. All references here are to T. 1 S., R. 13 W.

V. L. Cochrane, in the SW. ¼ NW. ¼ sec. 11, reports "17 feet of fire clay and red clay." The so-called fire clay is possibly the same as the buff clay in Mr. Norris's well.

Mr. Rowland, on the NW. ¼ SW. ¼ sec. 11, reports "22 feet of fire clay and red clay." This section without doubt exposes the same beds as does that given by Mr. Cochrane near the blacksmith shop.

Mr. Rowland also reports, from the SW. ¼ NW. ¼ sec. 11, "13 feet of fire clay and yellow clay, with from 2 to 4 inches of ferruginous sandstone interbedded."

Mr. S. E. Emerson, in the NE. ¼ NE. ¼ sec. 11, reports the following well section:

Section of well in NE. ¼ NE. ¼ sec. 11, T. 1 S., R. 13 W.

	Feet.
Red clay	3½
Gray "fire clay and black clay"	20
Gray clay	18

These gray clays and so-called fire clays are probably the same as the buff clays passed through in Mr. Norris's well. If this supposition is correct, these sections show that the buff clay is a widespread bed, underlying all the higher grounds east and southeast of Mabelvale, and probably a much wider area still, while it is cut out in the low grounds along the streams. Should there be a demand for these clays they will be found most accessible in sec. 3 and on the lower grounds about the bases of the ridges, where they are not obscured by a covering of gravel and sand and soil.

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LITTLE ROCK DISTRICT.

BRICK CLAYS

The folded Paleozoic rocks pass beneath the city of Little Rock, and on these folded beds rest the Tertiary clays and sands of the southwestern part of the city. It should be observed also that these Tertiary beds are nearly horizontal, that they thin out toward the north, and that similar beds underlie the region south of Fourche Mountains.

At several places in the city of Little Rock the folded Paleozoic rocks may be seen standing almost on end. The famous "little rock" itself, on which rests the south end of the railway bridge at the foot of Main street, is a folded and wrinkled Paleozoic bed.

Only a few paces south of the river bank these older beds are not exposed, but the surface is made up of loose materials. One of the best sections seen near the center of the city was exposed when the excavations were made for the foundations of the Masonic Temple, on the corner of Fifth and Main streets, in June, 1890. The section exposed was as follows:

Section in excavation for Masonic Temple at Little Rock.

	Feet.
1. Mottled red clays with chert pebbles, becoming more sandy at the base	7–9
2. Reddish-brown clayey sand with brown chert pebbles	2–3
3. Red, gray, and white mottled plastic, sandy clay with a few large and angular sandstone fragments at the top of the bed (exposed)	3

The upper surface of No. 3 is irregular, as if it had been eroded before the overlying beds were laid down upon it. These are probably the overwashed portions of the Tertiary series, the equivalents of which on the Atlantic seaboard are called the Appomattox formation. These rehandled beds of mottled clays, sands, and gravels are found at the surface in nearly every part of the city. They are well exposed in the cuts, even on the top of Capitol Hill, in the vicinity of the school for the blind, and at many other places. Below these gravelly beds lie the undisturbed Tertiary strata, which in and about Little Rock consist chiefly of limestones, shales, or clays, and sands.

Mr. C. E. Siebenthal, while in the employ of the Arkansas Survey, collected many data regarding the geology of southwestern Little Rock. He is of the opinion that there are four pretty constant and well-defined beds in the series of sediments resting upon the Paleozoic rocks. These are, beginning at the base, (1) yellow calcareous clay or marl; (2) dull gray fossiliferous limestone; (3) soft, dark unfossiliferous shale; (4) olive-green clay, probably derived by weathering from No. 3. Above this type section are found various combinations of sands and gravels and soil.

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Of these beds the ones of interest in connection with the subject of clays are the shale bed (No. 3) and the olive-green clay. The green clay is well exposed on the Seventh street pike, between West Spring street and West Sherman street, where it rests upon upturned Paleozoic rocks, which are exposed at this place. The following exposures and well records show the depth of the shales and clays at various points in the city:

Section in D. T. Coffman's well, at northwest corner Eighteenth and West Sherman streets, Little Rock.

	Feet.
1. Soil, gravels, and white clay	16
2. Soft shale, yellow above, blue below	14

West of the railway the olive-green clay is exposed in the road cut near the Catholic cemetery, in the gullies south of the cemetery, in the gully west of the hospital, and in another gully about 500 feet southwest of the hospital. It is also exposed in the bed of the branch just east of the hospital, and also toward the top of the ridge to the east.

The following is the record of a well put down west of the railway, about 300 feet northeast of the center of the south side of sec. 8, T. 1 N., R. 12 W., as reported by Mr. Siebenthal.

Section of well in sec. 8, T. 1 N., R. 12 W.

	Ft.	in.
Gravel and sand	6	
"Mulatto" clay	8	
Gray clay		10
Yellow clay	10	
Gravels and sandy clay	8	

East of the railway near the center of sec. 16, T. 1 N., R. 12 W., there are several exposures of the shale and of the olive-green clay. On the east slope of the ridge that runs along the east side of sec. 16 this same green clay is exposed here and there. It is exposed also in the gullies beside the road leading southwest from the Arch street pike, in the SW. ¼ sec. 15.

A well on the east side of the Arch street pike, 200 feet south of the northern edge of sec. 15, passed through soil, gravel, yellow clay, and tough blue clay, and got water at 27 feet in gravel. This clay bed is probably the same as that exposed in the gully on the slope of the hill below, where the road turns southwest from the Arch street pike.

A well at the southeast corner of Arch and Twenty-third streets passed through 8 feet of gravel and sandy clay and 10 feet of yellow and blue Tertiary clay. This is doubtless the same blue clay bed again.

At the end of the ridge east of the Rapley house and north of Pettifer's brickyard the olive-green clays are well exposed to a thickness of 40 to 45 feet. The olive-green clay and dark shale were found in

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wells and cisterns dug about Cumberland, Rock, Twentieth, and Twenty-first streets.

The following records were gathered by Mr. Siebenthal:

A well at Fifteenth and May streets passed through the Tertiary shale.

A well near the northwest corner of Thirteenth and Jones streets passed through 10 feet of soil and gravel and 18 feet of shale.

A well 14 feet deep at Fourteenth and Marshall streets passed through dark shale most of the way.

A well at the southeast corner of Twenty-seventh and Wolfe streets passed through 10 feet of gravel and sandy clay and 20 feet of dark Tertiary shale.

A well on Mr. Robert's place, Twenty-second street, between Commerce and Sherman, passed through 19 feet of soft Tertiary shale, and two other wells in adjoining lots to the east penetrated 60 feet of the same soft shale.

A well at the corner of Sixth and College streets passed through 30 to 35 feet of dark Tertiary shale.

A well bored by the Cotton Belt Railway Company on Rector avenue between Third and Fourth streets passed through the following:

Section in well of Cotton Belt Railway Company, Rector avenue, Little Rock.

	Feet.
Soil	12
Dark Tertiary shale	20
Paleozoic shale	29
Sand (?)	6

A well on Ninth street opposite the arsenal is reported by the digger to have the following section:

Section on Ninth street near the arsenal, Little Rock.

	Feet.
Soil and clay	20
Tertiary shale	8
White gravel	4

These facts and others not here given lead to the belief that the Tertiary clays follow the brow of the hill where the Arch street pike descends the slope about the middle of sec. 15, encircle the narrow valley that heads about the corner of Nineteenth and High streets, pass around it, and thence extend southward along the slope of the hill that runs along the east side of sec. 16, return northwestward along the valley through which the Iron Mountain Railway passes, appear again in the vicinity of the hospital on the west side of the railway, and thence around the hills west of the hospital. Of course, it is understood that these beds are nearly horizontal and that they pass right through the hills mentioned and have their edges exposed only on the slopes of the ridges. Almost everywhere, however, the

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outcrops are concealed by the soil and surface materials that have fallen down over them.

The elevation of the outcrop varies somewhat, but it lies for the most part between 260 feet and 302 feet above sea level.

In and near the city of Little Rock there are only a few places at which the clays can now be worked advantageously. This condition is due to the value of the land for building purposes, and not to any defect of the clays themselves. In spite of this it is possible that there may be places in the southwestern part of the city where the clays could be worked, while the nearness to market and to transportation would be in favor of such an enterprise.

On the south side of the river there is a brownish-yellow brick earth similar to that which forms the surface in sec. 28, T. 2 N., R. 12 W., overlying the other clays in different places west and south of Little Rock.

Between the high shaly hills on which the asylum for the insane and the reservoir of the city waterworks have been erected and the river there is a narrow strip of this same brownish-yellow clay. It lies in a long, narrow belt between the hills and the bottom land of the river. At Ward's old brickyard this brick loam rested directly upon a red sand. The section is as follows:

Section at Ward's old brickyard, Little Rock.

	Feet.
Brick earth removed at other places in the same belt	2
Stiff, hard red sand	4
Light iron-gray or yellowish sand	5

Between the point where the St. Louis, Iron Mountain and Southern Railway crosses Sixteenth street and the outcrop of the blue shales and quartz ledge at Nineteenth street a small deposit of this brownish-yellow brick earth appears to have been laid down in a sort of pocket among the shales, with its opening toward the south. The yellowish loam here has a depth of about 3 feet.

Another small deposit of the same material is found on the corner of Rector avenue and Eighteenth street. Here the brownish-yellow loam has a thickness of 2 to 3 feet. It is underlain by a bluish pebbly clay, mixed with sand. A well bored through this clay shows it to have a thickness of 19 feet. It is underlain by sandy clay. The underlying sandy clay is seen in the bottom of a small stream that runs along the south side of the old Bragg brickyard. The clay covers only a small area, most of it lying between gravel ridges.

On Arch street between Twenty-fourth and Twenty-sixth streets, at C. W. Clark's old brickyard, the brick clay was about 2 feet thick before it was exhausted, and was underlain by a stiff, bluish-red, streaked clay containing pebbles, which is said to be underlain by gravel.

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The greater portion of a well close to Clark's yard, 23 feet deep, passed through gravel, below which lay black mud. Another well, 16 feet deep, does not reach the black mud, but ends in the gravel.

JOINT CLAYS.

The next clay below the brownish-yellow brick clay is a stiff, hard clay having a tendency to break into small cuboidal fragments when exposed to the air. Its tendency to break is the chief objection to its use for manufacturing purposes. Ware containing any of this "joint" clay, as it is called, is likely to break in drying.

This joint clay varies somewhat in different places as regards color, having a blue or red tint according to its position, but the color has no apparent effect on its texture or its tendency to break when exposed to the drying action of the atmosphere. It appears to be very persistent, being found in nearly every opening in the district that passes through the upper beds. It is not confined to the brownish-yellow brick-earth area, but underlies the chocolate clay and some of the gravels.

In the district north of the river this joint clay is red and is seen in the stream running through the small bayou on the north side of Big Rock, where it underlies 2 feet of chocolate clay. In the wagon road near the Fort Smith crossing of the St. Louis, Iron Mountain and Southern Railway it varies from 3 to 5 feet in thickness and overlies a red sandy clay. In Mr. Vestal's portions of secs. 26 and 27, T. 2 N., R. 12 W., it lies near the surface. In the NE. ¼ NE. ¼ sec. 17, T. 2 N., R. 11 W., the clay underlying the brownish-yellow loam is very compact.

In the NE. ¼ NW. ¼ sec. 21, T. 2 N., R. 11 W., the clay underlying the brownish-yellow loam is a whitish-yellow and blue mixed sandy clay 20 feet thick and rests upon 12 feet of mottled clay.

On the south side of the river a blue clay underlies the other clays at most places where deep cuttings have been made. This clay, which lies just below the brownish-yellow surface clay, is a light-blue iron-stained clay containing quantities of pebbles and sand and nodules of limonite.

The underlying clay on the corner of Rector avenue and Eighteenth street is bluish gray and contains pebbles. At this place it is 19 feet thick. It is also seen in the bank of a small stream a short distance south of this place.

At C. Clark's old brickyard the brick earth is also underlain by this light-blue sandy clay. This same blue clay extends southward over the ground formerly used as a brickyard on the south side of Twenty-fifth street.

In the banks of the small stream that runs through the cemetery and westward across the Sweet Home turnpike, close to the Confederate soldiers' cemetery, there is a heavy deposit of a stiff, red joint clay.

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On the Arch street turnpike a little west of the place where the new road joins the turnpike a bed of blue and red mottled joint clay is exposed in a gully washed out by the rain.

For practical purposes these joint clays are not in much demand. Their tendency to "joint" or break up into small blocks whenever exposed to the weather makes their use difficult for any purpose except with great care, and even then no reliance could be placed upon them if worked alone.

If judiciously mixed with other clays they might be used for some classes of ware. A mixture of the stiff red clay and the brownish-yellow surface clay has been successfully used for making flower pots. A few lengths of drain tile, turned upon the potter's wheel, dried and burned very satisfactorily.

CHOCOLATE CLAYS.

The chocolate clays are found only in remnants or patches in various parts of the district.

At the union depot in Little Rock the chocolate clay forms the surface of the flat bottom of the cove in which the depot is situated. It has here a thickness of 2 to 3 feet.

In the small valley formed by the stream crossing the Sweet Home turnpike and skirting the southern side of the gravel ridge in the SE. ¼ sec. 11, T. 1 N., R 12 W., the chocolate clay is found on both sides of the stream and has a thickness of from 1 to 2 feet. On the hill at the tollgate between this stream and Fourche Bayou, about one-half mile from the place just mentioned, the same bed of chocolate clay appears.

The following section shows the relation of the clays at this hill:

Section at hill at tollgate.

	Feet.
Chocolate clay	3
Red clay	6
Blue clay.	

In Big Rock Bayou, in sec. 21, T. 2 N., R. 12 W., chocolate clay 2 feet thick overlying a blue clay occupies the greater part of the bottom lands around the bayou.

A partial analysis of the clay northwest of the union depot at Little Rock shows the following constituents:

Analysis of chocolate-colored clay northwest of union depot, Little Rock.

[J. P. Smith, analyst.]

Silica (SiO_2)	70.05
Alumina (Al_2O_3)	14.56
Ferric oxide (Fe_2O_3)	6.20
Lime (CaO)	.74
Magnesia (MgO)	1.12

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Potash (K_2O)	Not determined.
Soda (Na_2O)	
Loss on ignition	4.45
	97.12
Sand, very fine, but some coarse particles	11.83
Water at 110°–115° C	4.48

When the chocolate clay is washed, it makes a smooth paste of uniform color. This may probably form a good base for the manufacture of some classes of terra-cotta ware, but great care must be taken to see that it is dried at a uniform rate over all the work, as otherwise the clay has a tendency to break into small blocks.

A portion of the chocolate clay found in the valley at the union station was washed, and the slip so formed was allowed to stand for some time. The surplus water was filtered off and the whole was allowed to stand for two weeks. On drying it formed a smooth-surfaced even-textured clay and retained its characteristic chocolate color.

BOTTOM CLAYS.

The bottom lands that lie along Fourche Bayou and form Fourche Island are overlain in many places by a dark-bluish clay. On drying this clay becomes ashy gray and exhibits patches of iron or rust stains. When wet the clay is tough and plastic, and in drying it becomes hard and shows a tendency to crack where exposed to the heat of the sun.

An exposure of this clay is seen in the stream along the track of the St. Louis, Iron Mountain and Southern Railway, near the point where that road crosses Fourche Bayou, in the NE. ¼ SE. ¼ sec. 17, T. 1 N., R. 12 W. In this stream the clay bed is about 4 feet thick and extends along the railroad for nearly a quarter of a mile. It is also shown at various other places in the cuttings throughout the bottom lands.

This clay is comparatively free from sand and when wet is very tough. When worked properly it may be used for making a good grade of pressed front or ornamental bricks and may possibly be utilized for the manufacture of ordinary drain tile. In appearance and texture, as well as in position and apparent origin, this clay greatly resembles the clays of the bottom lands of Terre Noir and Bradshaw creeks, which were formerly used in the manufacture of bricks and drain tiles by Maj. Jesse A. Ross at his brick and tile factory near Arkadelphia.

In working this clay considerable attention will have to be paid to its proper mixing and tempering, and also to the drying of the bricks or tiles after they have come from the machine.

This clay will work better and easier if dug in the fall and worked over during the winter preparatory to its final tempering and manufacture in the following summer. The low-lying position of the pits will require the clay that is to be thus worked to be removed to a

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higher situation, where it will be beyond the reach of the overflow of the bayou during the late winter and early spring rains. It will be an advantage to house the clay in covered pits, where it can be protected from excessive wet and where at the same time it will not become too dry for working. If it contains a considerable quantity of its natural moisture, less work will be required in mixing and grinding and a much better final article will be produced.

Like the other clays found in the bottom lands of the State, this clay holds a considerable percentage of water, and at the same time it parts with the water very slowly. For this reason it will be necessary to work this clay in as dry a condition as possible. The slow parting with its combined water renders the drying of the bricks and tiles made of this or similar clays a rather long process and one which must be very carefully attended to. Such clays can be best dried under cover, in sheds so constructed that, as far as possible, a uniform amount of air and heat will be allowed to come in contact with the newly made bricks or tiles and strike them as equally as possible. At some seasons of the year, and for reasons given above, an artificial drier may probably be the most advantageous. Probably the drier may be economically used at all times, as clays of this class can not be dried in the air sufficiently to be ready for the kiln within fifteen to twenty days. Great care must be taken that the bricks or tiles are sufficiently dry before they are placed in the kiln. If not thoroughly dry when put into the kiln, the bricks will crack and the tiles have a tendency to split longitudinally.

M'ALMONT DISTRICT.

West of the village of McAlmont, in the center of sec. 16, T. 2 N., R. 11 W., on the line of the St. Louis, Iron Mountain and Southern Railway, and in the NE. ¼ NE. ¼ sec. 29, T. 2 N., R. 11 W., the railway crosses a bank of clay running in a northwest-southeast direction. The northern boundary of this field begins near Tremble Lake, in the SW. ¼ SW. ¼ sec. 9, T. 2 N., R. 11 W., and passes northeastward, curving gently round it until it crosses the St. Louis, Iron Mountain and Southern Railway 1 mile north of McAlmont. It there crosses the Memphis wagon road and, turning somewhat abruptly, comes west, crossing the wagon road to Galloway, a short distance east of McAlmont. The bank then curves round toward Ink Bayou. It follows the edge of the bayou for some distance and again crosses the public road and railway in the SE. ¼ sec. 20, T. 2 N., R. 11 W. This area is overlain to a great extent by a brighter colored loam than that found in the old brick field around Argenta, and from appearances it seems capable of making a finer brick.

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This bank is not altogether composed of yellowish loam. North of McAlmont the loam gives place to a stiff clay, which changes in color from bright red to drab and dark red as it approaches the outer point of the area comprised within the above limits. This clay, although differently colored, is apparently of the same nature. It is plastic, greasy to the touch, and works smoothly. Each color works into the other, forming a perfectly homogeneous mass. A well bored through the red clay in the SE. ¼ SE. ¼ sec. 9, T. 2 N., R. 11 W., shows it to have a thickness of 12 feet and that it rests upon fine sand.

In a ditch along the side of the railway and between it and the Memphis wagon road three beds are exposed. These clays are red, drab or gray, and bright red. The red clays at the bottom do not appear to have the same texture as the others. Where exposed to the air these clays become dried and show a tendency to break up into small pieces, somewhat in the same style as the joint clay, but when wet they are stiff and tenacious.

This clay bank follows the same general course as that just mentioned. It begins at Clear Lake, and from that point a mulatto sand succeeds it to the Galloway road at McAlmont. West of McAlmont the face of the bank becomes somewhat paler in its upper division. The light-colored material forms no great proportion of the bank, and in the many cuttings made by the small streams and rain the red clay is seen everywhere underlying it. Where the bank is crossed by the public road west of Buchanan's the light-colored and mulatto soils appear to be wanting in the face and are confined to the middle level of the country, and form a terrace, the edge of which is seen on the road a short distance west of Buchanan's, where it overlies a red silty sand and has a depth of 3½ feet. It, however, gradually disappears toward the west, and at the old graveyard on the Little Rock and McAlmont wagon road, about 2 miles east of the lower railroad bridge over Arkansas River, it is replaced by this red sand. The underlying clays in this field are not easily determined.

CLAY INDUSTRY.

The various kinds of clays found in Pulaski County have already been discussed. They include the kaolins of Fourche Mountain, pottery clays, clay shales suitable for the manufacture of paving bricks and fire bricks, and the more common surface clays suitable for the manufacture of common building bricks. Common brick clay is the only clay in the county now used, and Little Rock the only place where it is manufactured into bricks.

There are at present three brick plants in Little Rock engaged in the manufacture of brick. One of the largest plants is the Arkansas Brick and Manufacturing Company, established in 1897. The plant is well equipped with modern machinery for molding, drying, and

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burning. Stiff-mud and dry-pressed bricks are made. The stiff-mud bricks are molded in a Chambers machine and the dry-pressed bricks in a Ross-Keller dry press. The bricks are dried in a Standard drier and burned in Swift's patent up-draft grate kilns. It requires forty-eight hours to dry and eight to ten days to burn the bricks. Ten kilns, 72 feet by 24 feet inside measurement, are in use. The output of the plant is 150,000 stiff-mud and 25,000 dry-press bricks a day.

ST. FRANCIS COUNTY.

GENERAL GEOLOGY.

St. Francis County is divided into three natural subdivisions—(1) the eastern, or St. Francis River bottom; (2) the central, or Crowleys Ridge; and (3) the western, or the prairies.

The St. Francis River bottom is a flat area which is but 212 feet above sea level at Madison, on St. Francis River. East of this the country rises somewhat. The elevation of Forrest City, on the west side of Crowleys Ridge, is 251 feet. East of the ridge the surface material consists entirely of alluvial sand and silt.

The Chicago and Rock Island Railroad, which runs from Memphis to Little Rock, crosses Crowleys Ridge at Forrest City. The following interesting section is shown along the railroad from Madison, on St. Francis River, to Forrest City:

Section of Crowleys Ridge at Forrest City.

	Feet.
Loess (unstratified)	10
Dark loam, a phase of the loess	3
Yellow clay loam, a phase of the loess	10
Loess unstratified, containing irregular lime concretions	6
Stratified loess, bedding brought out in narrow bands by yellow iron-oxide coloring, containing many small land shells, also many round lime concretions of all sizes up to that of a base ball, the whole bed becoming more and more sandy toward the base	16
Hidden	2–3
Gravelly sand, streaked yellow with iron stain and cross-bedded	3–4

Still farther east, at a lower elevation than the base of the above section, the following section was obtained:

Section 1¼ miles east of Forrest City.

	Feet.
Loess (unstratified)	10
Dark loam, a phase of the loess	3
A reddish-yellow phase of the loess	6
Loess, indistinctly stratified	15
Yellow clay loam	3
Fine drab argillaceous sand	3
Coarse gravel (Lafayette)	5
Gray sand, cross-bedded in places and elsewhere interstratified with thin layers of light-drab clay	2
Dark to black sand, very fine, containing lignite, the dark color being due to carbonaceous matter	2–3

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On the east side of Crowleys Ridge, near the mouth of Big Crow Creek, and also in the bed of the creek about one-half mile from its mouth, there is a series of calcareous marine deposits containing numerous Tertiary fossils, which belong either to the Jackson or Claiborne horizons. The collections which have been made contain about an equal number of Jackson fossils and of fossils of Claiborne age. While the exact horizon may be somewhat doubtful, the fossils prove conclusively that the strata belong to the lower Tertiary beds.

The fossils found in the strata along Big Crow Creek, east of Forrest City, have made it possible to determine the age of the older strata along Crowleys Ridge. The ridge is, therefore, a remnant of the old Tertiary plain which once extended unbroken from the foot of the Paleozoic hills in eastern Arkansas eastward to the present bluffs east of Mississippi River.

CLAY DEPOSITS.

The clays of St. Francis County are the common brick clays found along the top and sides of Crowleys Ridge and the yellow clay loam of the prairie country west of the ridge.

Crowleys Ridge throughout the county is capped with loess, which is found in different phases. In the railroad cut east of Forrest City there are no less than four different varieties of the loess. In places it is a buff to gray nonstratified mass, containing a large percentage of lime concretions and land shells. Both above and below lie beds of stratified loess, which in places is a reddish-yellow clay loam, containing little or no lime carbonate and free from shells. The yellow clay loams of the loess are much better adapted to brick manufacture. The bricks burn to a solid red and are much stronger and stand more heat than bricks made from the calcareous loess.

The country west of the ridge has a surface covering of yellow clay similar to the yellow clay of the loess, but of much later age. In places its thickness ranges from about 15 feet at the western edge of St. Francis County to 40 feet or more near the foot of Crowleys Ridge.

The persistency of the surface clay is shown in the following well sections:

Section of well at Palestine.

	Feet.
Red clay	12–14
Quicksand	12–14
White clay	6– 8
Heavy gravel	12

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Section of well at Brinkley, about 3 miles west of St. Francis County.

	Feet.
Yellow clay	12
Yellow sand	17
Blue mud	1
Quicksand	6
Hard clay	25
Coarse gravel	(?)

The yellow surface clay which occurs so extensively over the prairie region west of the ridge forms in places the limonite buckshot land.

Below are given three analyses of the brick clays from St. Francis County:

Analysis of loess soil from Crowleys Ridge, at Forrest City.

[J. P. Smith, analyst.]

Silica and insolubles	76.30
Ferric oxide (Fe_2O_3) and Alumina (Al_2O_3)	16.86
Lime (CaO)	1.00
Magnesia (MgO)	1.22
Potash (K_2O)	.54
Soda (Na_2O)	.89
Phosphoric acid (P_2O_5)	Trace.
Loss on ignition	2.83
	99.64

Analysis of buckshot clay from Goodwin Prairie, 4 miles northwest of Goodwin station.

[J. P. Smith, analyst.]

Silica (SiO_2)	82.52
Alumina (Al_2O_3)	7.50
Iron oxide (Fe_2O_3)	4.32
Lime (CaO)	Trace.
Magnesia (MgO)	.40
Potash (K_2O)	.52
Soda (Na_2O)	.63
Manganese (MnO)	Trace.
Phosphoric acid (P_2O_5)	Trace.
Loss on ignition	3.64
	100.34
Water at 115° C	7.82

The following sample was taken from the material about a newly dug well about 4 miles northeast of Goodwin station, on the railway:

Analysis of hardpan from Goodwin Prairie.

[J. P. Smith, analyst.]

Silica (SiO_2)	84.04
Ferric oxide (Fe_2O_3)	3.70
Alumina (Al_2O_3)	6.32
Lime (CaO)	.34

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Magnesia (MgO)	Trace.
Potash (K_2O)	0.91
Soda (Na_2O)	.80
Manganese (MnO)	Trace.
Phosphoric acid (P_2O_5)	.00
Loss on ignition	3.32
	99.43
Water at 115° C	1.40

CLAY INDUSTRY.

The only clay product manufactured in the county is common building brick, made from the loess by the Choctaw Brick and Tile Company, of Forrest City. The clay is hauled from the pit to the machine by a team and scraper, mixed in a steam pug mill, and molded in a Chambers end-cut, stiff-mud machine. The bricks are dried by steam, which requires one to two days. They are burned in up-draft kilns, having a capacity of 200,000 bricks. Wood is used as fuel. The plant has a capacity of 20,000 bricks a day.

SALINE COUNTY.

GENERAL GEOLOGY.

Saline County has within its borders rocks of two widely different geologic ages. The northwestern portion of the county is covered with Paleozoic shales, sandstones, and novaculites, much folded or standing on edge, and intersected by a vast number of quartz veins; while the southeastern part is of soft and usually uncompacted and horizontally bedded Tertiary sands, clays, and gravels, except in parts of T. 2 S., R. 14 W., where eruptive rocks come to the surface. The line separating the Paleozoic and Tertiary areas runs through the county in a northeast-southwest direction. The St. Louis, Iron Mountain and Southern Railway follows the dividing line approximately parallel with and from 1 to 4 miles northwest of it. The region of Paleozoic shales and sandstones to the northwest was the dry land forming the shores during Tertiary times, when the sands and clays that lie to the southeast were being deposited in the waters which at that time covered all southern and eastern Arkansas.

CLAY DEPOSITS.

DISTRIBUTION OF THE CLAYS.

In the northern and western parts of the county pottery clays are not likely to occur in abundance. They may possibly be found in occasional local pockets, where the clay shales have decayed, or in "slashes," where the water has leached out local accumulations; but the great pottery clay beds lie south and east of the old shore line re-

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ferred to above. In the river bottoms also, especially along Saline River, the immediate surface soil includes here and there "buckshot" clays, which furnish rather poor pottery clays.

CLAYS ABOUT BENTON.

The clay pits opened in the vicinity of Benton have aided a comprehension of both the general and detailed structure of this part of the State. These pits are all in T. 2 S., R. 15 W. The sections which they represent are here given in detail, beginning with the Hicks pit in the NE. ¼ NE. ¼ sec. 12.

HICKS CLAY BANK.

The Hicks clay bank, formerly known as "the old Leach bank," was the first clay deposit opened in the neighborhood of Benton, and for several years was the only source of supply for pottery clays at that place. Early in 1889 the old pit was reopened by Mr. J. Howe, and the clay was mixed with clay from other pits for use in his pottery. It is not used by itself in any of the potteries.

Section at the Hicks pit.

	Feet.
Sandy soil, capped with novaculite gravel	2
Sandy clay, with scattered pebbles; particolored and more sandy below	7
Drab potter's clay	20

The bottom of this clay had not been reached by the operations in progress at the time it was visited. The clay at different points of the pit varies in the amount of sand it contains. It is pinkish brown when first dug, but as it dries becomes light gray with a faint pink tinge. It has a slightly sweetish taste. It is wanting in body and will not burn to a solid stoneware. Only the Albany slip-black glaze can be used with it, all attempts hitherto made at salt glazing having resulted in failure owing to the inability of the ware to bear a sufficiently high heat. When subjected to a white heat it cracks and breaks in the kiln, and the pieces escaping destruction in this way are liable to air check in cooling. It may be very profitably manufactured into open ware, however, such as pots, churns, crocks, and milk pans, or into any article in which the liquid contents are not allowed to stand long. Unglazed ware made from this clay is very porous, and when glazed ware made of it cracks or chips so as to expose the body of the vessel it is found to be very absorbent, so that it can not be employed for ware that is to be used to hold liquids for any great length of time.

THE RHODENBAUGH CLAY BANK.

The Rhodenbaugh bank is in the SW. ¼ NE. ¼ sec. 12, T. 2 S., R. 15 W., about one-fourth mile south of the Hicks pit. A depression between this and the Hicks bank is filled with waterworn gravel.

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The sections at the two pits are practically the same, and the beds are the same, but there is a slight difference or local variation in the character of the clays themselves.

Section at the Rhodenbaugh clay bank.

	Feet.
Thin sandy soil with fine gravel	1
Ferruginous gravel with abundant coarse sand; clayey below	5
Light-drab potter's clay, the lower 2 feet of which is blue containing red patches of iron	10
Fine white sand	1½
Novaculite gravels, conglomerated	3
	20½

Below the pottery clay is a bed of brownish-yellow waterworn, novaculite gravel, much of which is cemented into a conglomerate. Near the upper surface or top of the 10-foot bed of clay there is a streak of black material 2 inches thick. The 2 feet of blue clay constituting the base of this bed contain numerous impressions of leaves and stems of plants and red patches. This 2-foot layer of clay is not used in the manufacture of pottery but goes to the waste bank with the gravel. This blue clay might, if mixed with sufficient quantity of sand, be used for the manufacture of bricks. Bricks as a rule do not require the same degree of firing as stoneware, and the red material, if mixed properly, will be an advantage rather than a detriment to it, as it would serve to color the whole mass. This clay is rejected by the potters because the ware must be subjected to a prolonged white heat before it will take the glaze necessary to produce a marketable product, and under the high temperature required the red clay, which is highly charged with iron, would melt or turn black and make the ware unsightly and unfit for market. Great care must therefore be exercised to prevent any of this material from being mixed with the clean pottery clay.

The clay from the Rhodenbaugh bed is fine grained and of close texture. When moist it has a pinkish-brown color, which it loses on drying. Although sometimes used without any mixture the proprietors of the pit consider it very much improved by the addition of a little sand. The sand adds to the body and in burning enables the ware to take a hard finish. It will take either the Albany slip glaze or the salt glaze.

The bed of clay found in Rhodenbaugh's pit covers about 8 acres and thins out toward the south within a short distance of Rhodenbaugh's house.

The following is the section exposed in a well 36 feet deep in Rhodenbaugh's garden, in the NW. ¼ SW. ¼ sec. 12. The well does not strike the clay, although it penetrates the Tertiary and reaches Paleozoic rocks below. The mouth of the well is doubtless at a point below the clay bed.

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Section of Rhodenbaugh's well.

	Feet.
Waterworn gravel	12
Black clay, breaking up in flakes	4
Stiff, tenacious blue clay	20
Paleozoic sandstone at the bottom.	
	36

A well is reported to have been dug at Bernard Fiste's place, near the middle of the north side of sec. 13, about three-fourths of a mile east of Rhodenbaugh's pottery. In this well a pottery clay bed was struck at a depth of 45 feet. The bed is said to be 15 feet thick here and of dark color. The clay, which has been tested, retains its dark color after burning. Its occurrence at this place throws much light on the distribution of the pottery clays about Benton.

WOOSLEY CLAY BANK.

The Woosley clay bank is in the NE. ¼ sec. 1, on both sides of "the old military road" leading northeastward from Benton. The clay is 5 or 6 feet thick, but it thins out at the margins of the bed, which covers about 1½ acres. About 400 feet east of Mr. Woosley's house the following section is exposed in an abandoned clay pit:

Section at Woosley's clay pit.

	Feet.
Brown pebbly, iron-stained clay	4
Red sandy clay	6
Blue clay with red patches	2
Pottery clay	5
Grayish sand	4
	21

The following section is reported by Mr. Kennedy:

Section of pit at Woosley's pottery sheds.

	Feet.
Hard grayish sandy clay	4
Pottery clay	5
Light-grayish sand	6
Bluish joint clay at base.	

Mr. Woosley has opened another clay pit on the west side of the SW.¼ NW. ¼ sec. 1. The beds exposed are as follows:

Section in SW. ¼ NW. ¼ sec. 1, T. 2 S., R. 15 W.

	Feet.
Red sandy clay	4
Pottery clay	4

The well section at Woosley's pottery, reported by Call, is interesting as showing the relations of the potter's clay of his pit to the underlying blue joint clays of Eocene age. The section should be considered in connection with that at Womack's pit, in the village of Benton.

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Section of well at Woosley's pottery.

	Feet.
Gravelly and clayey sand	4
Potter's clay, becoming sandy below	10
Stratified blue or black joint clay	45

The well ends in the joint clay without penetrating it. Probably the clay is precisely equivalent to that found in the Benton well sections.

The section at Woosley's pit, as observed by Professor Call in June, 1891, is given below.

Section at Woosley's clay pit.

	Feet.
1. Light gravelly and sandy soil	1
2. Gravel bed, with much coarse sand	3
3. Red sandy clay with occasional pockets of clay	8
4. Snuff-colored potter's clay, upper foot containing pockets of red sand, lower 4 feet a bright-yellow potter's clay	12
5. Fine white sand with some clay	12
	36

The sands from No. 5 of this section were mixed with clays from No. 4. The pottery made of this combination was a well-bodied light-yellow ware with a metallic ring, and took a good glaze. Only a portion of this clay was worked and the pit was then abandoned by its owner, who now uses clay from a bed 500 feet north of Davis's pottery and west of the military road.

In appearance and in general structure the clay taken from Woosley's bed is like that found in the other clay deposits near Benton. It is light pinkish brown when moist and dries to a faint pink color. In working and burning it has the reputation of being, next to that from Rhodenbaugh's bed, the finest clay in the district. It burns to a solid stone body and takes both salt and Albany slip glaze.

DAVIS CLAY BANK.

The L. R. Davis pit (formerly Herrick & Davis) is in the NW. ¼ SE. ¼ sec. 2, on the northwest side of the old military road. The following section in a pit near the west end of the bank shows the relations of the several beds:

Section at the L. R. Davis clay pit.

	Feet.
Waterworn gravel	3
Red clay	4
Potter's clay	11
Ferruginous sandstone at the bottom.	

Nearly the same section is exposed in a well 50 feet deep a little east of the east end of the pit. In the well section the gravel is thicker and the red clay somewhat thinner, while the potter's clay remains the same.

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Below is given the section of a well at Mr. Herrick's house, east of Davis's clay pit, in the NW. ¼ SE. ¼ sec. 2, T. 2 S., R. 15 W.

Section of Herrick's well.

	Feet.
Waterworn gravel	4
Brown pottery clay	11
Coarse, white, sharp sand	25
Waterworn, iron-stained gravel	10
	50

The potter's clay thins out and disappears south of the road and about 50 yards south of Davis's pottery sheds. The clay burns to a white or cream color and may be glazed by both salt and Albany slip glaze.

HENDERSON CLAY BANK.

S. M. Henderson's bank is in the NW. ¼ NE. ¼ sec. 2, T. 2 S., R. 15 W., and underlies a brownish sandy gravel 3 feet in thickness and a blue sandy clay containing bright patches. This sandy clay is of variable thickness, but it averages about 3 feet. Beneath this bed lies the potter's clay, with a thickness of 14 feet. The color of the clay varies with the depth in the pit, ranging from light blue or pinkish on top to almost black at the base. The lower strata contain impressions of leaves and stems of plants. This clay burns to a stone body that readily takes both the Albany slip and the salt glaze.

About 300 feet east of Kirkpatrick's house a well at his brickyard shows the pottery clay to have a covering of 15 feet.

At Kirkpatrick's, on the west side of the NE. ¼ NE. ¼ sec. 11, a well 20 feet deep penetrates gravelly, sandy clay and ends in the potter's clay beds.

This bed is probably continuous eastward over the bottoms along the creek. Its dip is southeast, as is indicated by the occurrence of a similar bed in a well section three-fourths of a mile farther east, in the NE. ¼ NE. ¼ sec. 23, T. 2 S., R. 15 W., which is without doubt an extension of the same deposit.

Search has been made for these beds at various points in ravines and gullies along the hillside south of the Iron Mountain Railway depot at Benton, but none were found.

WOMACK CLAY BANK.

A stiff, dark, lead-colored clay appears in the town of Benton on the west side of Market street and between that point and the "old military road," in the NW. ¼ SW. ¼ sec. 11, T. 2 S., R. 15 W. The clay is at least 30 feet thick, as seen in the section given below (by Call), but its total thickness has not been ascertained. It gets darker as it is penetrated deeper.

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Section at Womack's clay pit, Benton.

	Feet.
Soil, sandy and gravelly	2
Gravel and coarse sand, highly ferruginous	6
Conglomerate; sand and fine gravel cemented with iron oxide	½
Blue or lead-colored joint clay, with scattered nodules of iron pyrites	30½
	39

The clay found in this pit occurs in the bottom of a dozen or more wells in the village of Benton. A well digger who had put down nearly all these wells exhibited a mass of clay from the bottom of one well (which stratum he said was reached in all wells attaining a depth of 40 feet or more) containing marine shells (*Turritella carinata*) of Eocene (Tertiary) age.

In certain portions of the pit, near its middle line, occasional nodules of iron pyrites occur. Mica scales abound in the cleavage planes and rarely crystals of selenite are seen.

The clay from Womack's pit is too stiff to be worked in ordinary pugs, and must be crushed by special machinery. A sample brought to the office of the Arkansas Geological Survey by Mr. Womack was somewhat streaked with iron, some of which seems to have infiltrated along the rootlets of plants.

This clay taken alone is not a distinctively good potter's clay, and ware made from it is not equal to that made from the clays of any other Benton pit. It gives a heavy body and cool cracks when salt glaze is employed. It is mixed with clay from Hicks's pit in the proportion of equal parts of each, and in this way makes a very fair gray pottery. It is highly probable that with some experimenting a method could be hit upon that would make it possible to utilize this fine bed of clay to better advantage. If no better use be found, it might be available for making vitrified bricks.

OTHER CLAYS NEAR BENTON.

In the southeast corner of the SW. ¼ NW. ¼ sec. 13, T. 2 S., R. 15 W., near Mrs. Butler's house, a well 65 feet deep passes through a bed of dark potter's clay 30 feet thick.

Section of well near Mrs. Butler's.

	Feet.
Red clay	4
Sand	24
Potter's clay	30
Waterworn gravel	7
	65

In the NW. ¼ SW. ¼ sec. 13 a well 800 feet south of Mrs. Butler's, just west of the road, is 20 feet deep but does not penetrate the potter's clay bed. The mouth of this well is about 15 feet above the mouth of Mrs. Butler's well.

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Section in sec. 13, T. 2 S., R. 15 W.

	Feet.
Red sandy clay	3
Joint clay	4
Blue sand	13
	20

In the NE. ¼ SE. ¼ sec. 13, T. 2 S., R. 15 W., at Bennett's pottery, a well 20 feet deep has the section given below.

Section of well at Bennett's pottery.

	Feet.
Soil	5
Clay	2
Red sandy clay	12
Blue sand at bottom.	

The well section at Mrs. Butler's and at other points south of the railway, taken in connection with the other observations, throws light on the distribution of the clay beds about Benton and throughout the region south of Benton. The relations of these sections to one another can be best shown by the profile given in fig. 16. This

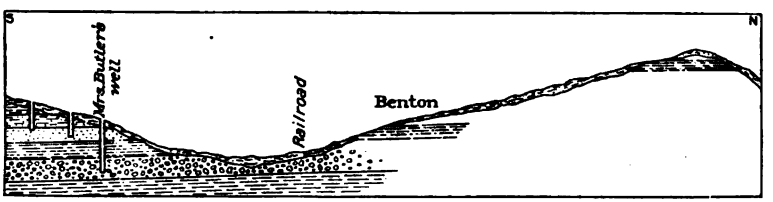

FIG. 16.—North-south section at Benton, showing relations of the clay beds north of the railway to those south of it.

section shows why pottery clay was not found either in the well south of Mrs. Butler or in that at Bennett's pottery. If these wells were carried down 25 feet deeper they would enter the bed penetrated at Mrs. Butler's.

On the hills west of Mrs. Butler's, at a point in the W. ½ sec. 14, but not precisely located, a well is reported with the following section:

Well section in sec. 14, T. 2 S., R. 15 W.

	Feet.
Clay and gravel	10
Clay with sand streaks	20
Sand	4

It seems probable that the sand found in the bottom of this well is the top of the sand bed that overlies the potter's clay, and that if the well were carried down 20 feet deeper it would enter the clay.

Mr. T. C. Hopkins also found an exposure of weathered potter's clay on the south side of the little stream about a quarter of a mile south of the Benton depot. This is about where one would expect to find the outcrop of the great bed on the south side of the valley.

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The elevations were observed (by aneroid barometer) at Mrs. Butler's and at the various clay pits north of the railway for the purpose of determining whether the clay pits were all upon the same bed, and to ascertain the dip of the beds.

Elevations of the pottery clay beds near Benton.

	Feet.
Rhodenbaugh's pit	340
Hicks's pit	350
Davis's pit	420
Woosley's pit	440
Bed in Mrs. Butler's well	325
Bennett's pottery	340
Henderson's pit	380

These elevations show that the beds have a gentle dip to the east and south and that the Rhodenbaugh, Hicks, Davis, Woosley(?), and Henderson pits on the north side of the railway track are in all probability on a bed of clay identical with the bed cut in Mrs. Butler's well. The slight differences of the clays found in the various pits are of a character that usually occurs in any deposit in passing from one point to another. The thinness of the beds and their irregularities are no doubt produced by the greater erosion to which the northwestern or landward edges of these soft beds have been exposed.

The Woosley bed appears to be higher than the others and to be only the small fragment of a bed which once overlay the region south of Woosley's, but which has all been removed by erosion except this remnant and its possible southward extension, which is to be looked for in the hilltops south of Mrs. Butler's well.

The beds opened north of the railway (except Woosley's) appear to be all parts of the same deposit, and in all probability the clay may be found in a long outcrop that will connect the Hicks, Henderson, Davis, and Rhodenbaugh banks with the well at Mrs. Butler's.

The sections and records given above relate only to the beds exposed in the immediate neighborhood of Benton. Most of the clays of these beds have been tested in one way or another. There is no reason for supposing that the valuable clay beds are confined to this locality, but the geology leads us to conclude that just as good deposits exist in other parts of the county. With a view to ascertaining as much as possible regarding the distribution of the potter's clays in the surrounding country the following observations are brought together here:

About the center of the SE. ¼ SE. ¼ sec. 3, T. 2 S., R. 13 W., there is a bed of clay on Robert Bigg's place that deserves special attention. The geologic observations at this locality were kindly furnished by Mr. E. C. Buchanan, of Little Rock, who made two trips to examine it, and who collected the sample whose analysis is given below. The

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clay outcrops at several places in the SE. ¼ SE. ¼ sec. 3. The outcrops are in a series of small gullies, from 2 to 7 feet deep, draining south and southeast and northeast. The section exposed is as follows:

Section at the Robert Bigg place.

	Ft.	In.
1. Sandy clay and gravel	2	6
2. Reddish clay	2	
3. Cream-colored clay	5	
4. Reddish sandstone		½
5. Cream-colored clay	10	

Mr. Palmer, who lives at the northwest corner of SE. ¼ sec. 3, says that he dug a pit 3 feet at the lowest part of the exposure of No. 5 without reaching the bottom of that bed. The beds seem to be horizontal.

The clay of the bottom bed (No. 5) has a conchoidal fracture, and is cream colored when first dug out, but on exposure to the sun it becomes nearly white. Beds of No. 3 and No. 5 are apparently about the same, but are separated by the thin layer of sand rock.

A well 55 feet deep, dug by Mr. Palmer at the point indicated, starts about 20 feet below the level of the clay and for that reason does not penetrate the bed. The clay is thus confined in this locality to the tops of the low hills, and the total area underlain by it here is about 20 acres. It is probable, however, that the same bed occurs in the surrounding hills, especially toward the east. The same bed is exposed at the spring just south of Mr. Bigg's house, where fragments of lignite overlie it.

The composition of No. 5 of the section at Robert Bigg's place (SE. ¼ SE. ¼ sec. 13, T. 2 S., R. 13 W.) is given below.

Analysis of clay from the Bigg place.

[L. R. Lenox, analyst.]

Silica (SiO_2)	63.29
Alumina (Al_2O_3)	18.19
Iron (Fe_2O_3)	6.45
Lime (CaO)	.31
Magnesia (MgO)	2.44
Manganese (MnO)	Trace.
Potash (K_2O)	.56
Soda (Na_2O)	Trace.
Water (loss on ignition)	9.47
	100.71

In the low ground about 2 miles southwest of Alexander, on the St. Louis, Iron Mountain and Southern Railway, potter's clays of a buff color are exposed in the ditch by the railroad. This exposure is at the foot of the railroad grade that descends from the summit next north of Bryant to Crooked Creek, and is 1¼ miles from Bryant. Again, potter's clay is reported on the railroad near Bryant, a short distance

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southwest of the station. The well sections at Bryant, however, do not show satisfactorily that such clays exist there. The well at the Commercial Hotel, about 50 paces south of the railroad, and 22 feet deep, has hard clay in the bottom, but it is not known whether it is a potter's clay. Another well, 22 feet deep, a quarter of a mile northeast of the station, has lumpy clay in the bottom, but it is probably not a good potter's clay. In the NW. ¼ sec. 24, T. 1 S., R. 15 W., a well 15 feet deep has 10 feet of pipe clay in the bottom. Nothing is known of its value. In the SE. ¼ sec. 13, same township, a well 30 feet deep has 10 feet of "joint clay" in the bottom.

At Zuber post-office, in the NE. ¼ sec. 5, T. 1. S., R. 15 W., there are two wells. One in a depression struck black shale 4 feet below the surface, and one on the slope above the sawmill struck black shale at a depth of 20 feet. In the débris from the latter are numerous lumps of potter's clay, resembling that at Benton.

In the NE. ¼ NW. ¼ sec. 36, T. 2 S., R. 16 W., at Mr. Cliff's, a well passed through the following section:

Section of Cliff's well.

	Feet.
Red clay and sand	4
Clay with fossil shells	20
Decayed limestone	2

The clay referred to was not seen by the writer, but it is possible that a portion of the bed, at least, may be available for pottery.

Clay beds, somewhat mottled on their exposed surfaces, occur in the NW. ¼ SW. ¼ sec. 19, T. 2 S., R. 15 W., but the Paleozoic rocks are exposed on the lower side of the hills that slope to the north in this quarter section. In the SW. ¼ sec. 20, of the same township, a well 25 feet deep penetrates beneath the topmost 4 feet an 18-foot bed of light-colored potter's clay containing streaks of sand near the bottom.

A well 40 feet deep in the middle of the east side of sec. 3, T. 3 S., R. 16 W., is said to be dug entirely in red and white pipe clay, through which there is a single black streak. No evidence was found of clay farther south in Saline County than where it is cut in this well. It should be remarked, however, that no well sections were found farther south. The surface is covered with fine quartz and novaculite gravel, which seems to form the slope of the hill on the south side of the small creek in sec. 10, T. 3 S., R. 16 W. In the NE. ¼ sec. 14 of this township 16 feet of clay is also reported in a well. This is in Hot Spring County.

Between the county line and Traskwood and thence northward on the Traskwood-Benton road for more than 4 miles the well sections show only sand or very sandy clays.

On Crooked Creek in the SW. ¼ NE. ¼ sec. 15, T. 1 S., R. 14 W., about three-fourths of a mile west of Collegeville, there is an exposure of blue, white, and variegated shales.

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Section on Crooked Creek.

	Feet.
1. Surface gravel and humus	3
2. Sandstone	1
3. Blue and white shales having a talcose or soapy touch	2
4. Light-colored shales, drying white and chalky	1
5. Blue clay.	

All these shales have a greasy feel and very much the same appearance in fracture and splitting. No. 4 of the above section was analyzed with the results given below.

Analysis of shale from Crooked Creek.

[Brackett & Smith, analysts.]

Silica (SiO_2)	82.45
Alumina (Al_2O_3)	11.80
Iron (ferric) oxide (Fe_2O_3)	.80
Lime (CaO)	.31
Magnesia (MgO)	.25
Alkalis (by difference)	1.60
Water (loss on ignition)	2.79
	100.00
Water at 110°–115° C	.21

The air-dried material contains 27.37 per cent of fine sand.

The following table brings together the analyses of all the pottery clays examined from the different clay banks at Benton, except that called kaolin on pages 196–197.

Analyses of clays from Benton, Saline County.

	Rhodenbaugh.	Davis.	Henderson.	Hicks.	Woosley.	Womack.
Silica (SiO_2)	72.44	69.95	71.09	65.79	64.49	66.23
Alumina (Al_2O_3)	18.97	22.34	19.86	23.92	23.86	22.31
Iron (ferric) oxide (Fe_2O_3)	1.59	1.44	1.81	1.94	2.11	2.12
Lime (CaO)	.18	Trace.	.11	.23	.31	.92
Magnesia (MgO)	Trace.	.08	Trace.	Trace.	Trace.	Trace.
Potash (K_2O)	1.35	1.28	1.45	1.15	.11	.04
Soda (Na_2O)	.91	.18	.81	1.08	1.82	1.59
Water (H_2O)	5.39	5.98	5.67	7.07	8.11	7.38
	100.83	102.25	100.80	101.18	100.81	100.59
Water at 110°-115°C	1.55	2.34	1.96	1.80	2.37	7.27
Sand	.26	.46	3.13	2.72	.19	.....

GENERAL CONCLUSIONS.

That Benton is well supplied with excellent clays for the manufacture of the common grades of stoneware and pottery is a fact established by the experience of many years. The clays there used, however, have a much wider distribution throughout the southern and eastern parts of the county than seems to be suspected. They have been found at Bernard Fiste's place, west of Rhodenbaugh's pottery, while the great bed cut in Mrs. Butler's well in sec. 13, T. 2 S.,

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R. 15 W., is simply the southward continuation of the beds opened north of the railway. The bed extends around the hills to the south, the outcrop being in the faces of the hills that look toward Saline River. It is exposed on nearly all the hillsides on the old military road running northwestward from Benton, probably extending to and beyond the borders of the county.

In the broad bottoms on the west side of Saline River the "buckshot clay" lies beneath the surface soil and good clays are not to be expected here in such localities within easy reach.

The Tertiary hills west of the Saline begin about the middle of the SE. ¼ sec. 20, T. 2 S., R. 15 W. The Tertiary clays encircle these hills north of the railway and west of the river, and the potter's clays will probably be found about the bases of these hills in the vicinity of Traskwood, on both sides of the railway. The geology of the region favors the supposition that the potter's clays occur also within the drainage of Hurricane Creek, in the southeastern part of the county.

Those who are in search of pottery clays in Saline and adjoining counties should bear in mind that such clays are at many places associated with leaf and other plant impressions and not often associated with marine shells. Many of the Saline County clays that are now regarded as but poorly or not at all adapted to the manufacture of common pottery need only more careful study and experimenting to make them available. That a clay can be used unmodified, just as it comes from the pit, is a mere accident, and while it is a fortunate one, we should not be satisfied to allow an industry to depend on it.

VARIETIES OF KAOLIN.

SALINE COUNTY KAOLIN.

The syenite area of Saline County lies in secs. 35 and 36, T. 1 S., R. 14 W., and in secs. 1, 2, 9, 10, 13, 14, 15, 16, 20, 21, 22, 23, 24, 25, 26, 27, 34, and 35, T. 2 S., R. 14 W. The margins of the crystalline rocks are covered by the Tertiary and Pleistocene deposits, which make up the remainder of the county southeast of the railway in Saline County.

The kaolins found in Saline County are of three varieties—(1) a compact variety, derived directly from feldspathic rocks by decomposition; (2) a pisolitic variety, found associated more or less intimately with the bauxite deposits, and (3) a claylike variety of sedimentary origin, found at Benton.

The first two of these varieties are not readily separable and will here be considered together.

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COMPACT AND PISOLITIC KAOLIN.

Kaolin exists in secs. 9, 10, 14, 15, 16, 21, 22, 23, 26, T. 2 S., R. 14 W., and probably in other places. The deposits in sec. 16 seem to be extensive, for kaolin is found here and there almost all over that section. In the SE. ¼ SE. ¼ sec. 16, T. 2 S., R. 14 W., it is exposed on the eastern side of a ridge, where it rests on syenite. This deposit has never been bored through and its thickness is unknown. Messrs. Nethercut, the proprietors, have quarried it on a small scale for building material. The coarser matter is used for building the outsides of chimneys and the finer is employed for lining flues and hearths. In carrying on these quarrying operations the material was penetrated to a depth of 15 feet near the upper edge of the deposit, but the kaolin had not been passed through.

In the NE. ¼ SW. ¼ sec. 16, 80 or 100 yards west of Mr. Sol. Nethercut's house, an excavation 8 feet in diameter and 15 feet deep was made for the purpose of testing the thickness of the kaolin, but the undertaking was abandoned before the bed was cut through. At Mr. Sol. Nethercut's house, near the northwest corner of the NW. ¼ SE. ¼ sec. 16, a well 18 feet deep shows a face of 10 feet of kaolin in the bottom of the well. This does not indicate the thickness of the deposit at this place, as the digging was stopped before the kaolin was penetrated.

Kaolin also overlies the syenite at many places in the SW. ¼ SE. ¼ sec. 16, T. 2 N., R. 14 W.

On the north side of the NE. ¼ sec. 16 there is a large deposit of kaolin which extends across the line into sec. 9. This kaolin varies somewhat in appearance in different positions. That on the eastern side of the SE. ¼ SE. ¼ sec. 16 is of two kinds. One bed is white or grayish white, having small specks and streaks of a gray material scattered through the white ground and occasional patches of iron stain. The other contains fewer gray patches, but is of a pale pinkish or brownish tint. The pink-tinted kaolin generally overlies the gray mottled material.

The deposits on the bank of the stream in the NE. ¼ SW. ¼ sec. 16, as well as those in the diggings and wells in this division of the land section, have generally a white, chalky appearance. It does not show so much iron staining or gray specks as the material found in the SE. ¼ SE. ¼. sec. 16.

The deposit found in the NE. ¼ sec. 16 and the SE. ¼ sec. 9 is a white and gray streaked material very similar to the lower gray-streaked bed in the SE. ¼ SE. ¼ sec. 16.

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Analyses of kaolins from sec. 16, T. 2 S., R. 14 W.

	NW. ¼ SE. ¼.	SE. ¼ SE. ¼.
Silica (SiO_2)	45.62	44.97
Alumina (Al_2O_3)	34.18	38.87
Iron (ferric) oxide (Fe_2O_3)	4.05	1.34
Lime (CaO)	.20	.25
Magnesia (MgO)	Faint trace.	Faint trace.
Potash (K_2O)	.53	.20
Soda (Na_2O)	.54	.34
Manganese (MnO)	.17	Strong trace.
Water	13.82	14.37
	99.11	100.34
Water at 110°–115° C	1.46	5.51

The distribution of pisolitic kaolin in this district is probably nearly the same as that of bauxite, and the map accompanying Dr. C. W. Hayes's report on Arkansas bauxite[a] shows the distribution of bauxite and of crystalline rocks in Saline County so far as they are known. As in the other bauxite areas, the pisolitic kaolin is to be sought well below the surface, where it is probably of better color, softer, and freer from iron than nearer the surface.

TERTIARY KAOLIN AT BENTON.

Beds of kaolin that are formed by the decomposition of feldspar are commonly irregular and pockety in form, owing to the irregularity with which the feldspathic rocks decay. After the rocks have decomposed, however, the kaolin is liable to be washed away, and when it settles to the bottom of a body of water it will be spread out in horizontal beds like other sediments. It seems probable that some, possibly all, of the sedimentary kaolins are formed in this way.

At Benton two beds of kaolin are associated with the Tertiary deposits. One of these is exposed on the north side of the stream in the SW. ¼ SW. ¼ sec. 36, T. 1 S., R. 15 W., on the slope of a hill about 600 feet northwest of Howe's pottery and at intervals along the face of the hill for several hundred feet. It is about 9 feet thick and looks like a firm white clay. Above it is 6 feet of coarse, indurated red sand, and above this is a thin sandy soil.

The association of this bed with the pottery clays and its attractive appearance have led to attempts to utilize it for making the ordinary coarse pottery usually manufactured at Benton, but as it requires treatment different from that given the common pottery clays, its use for this purpose was soon abandoned.

[a] Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 3, 1901, Pl. LXI.

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Analysis of Tertiary kaolin from Benton.

[R. N. Brackett, analyst.]

Silica (SiO_2)	48.34
Alumina (Al_2O_3)	34.58
Iron (ferric) oxide (Fe_2O_3)	1.65
Lime (CaO)	.81
Magnesia (MgO)	Trace.
Potash (K_2O)	.44
Soda (Na_2O)	1.26
Loss on ignition (water)	12.94
	100.02
Water at 110°–115° C	2.20

It is to be hoped that other efforts will be made to turn this bed of kaolin to account. It should be remembered that no kaolin can be used just as it comes from the pit; each one requires a treatment of its own, and he who experiments with this variety until he understands how to treat it will probably be well rewarded for his trouble. It must not be expected, however, that a kaolin that contains so high a percentage of iron will burn white. If mixed with a poor sandy clay it will probably make an excellent pottery clay.

CLAY INDUSTRY.

Eagle Pottery Company.—The plant of the Eagle Pottery Company is located 1½ miles northeast of Benton. It has a capacity of 800 to 900 gallons daily. Four turners are employed, some of whom turn 300 gallons a day. Twenty-two pounds of clay are used in a 5-gallon vessel and 6½ pounds in a 1-gallon vessel. The smaller the vessel the more clay is used per gallon.

The ware is burned in a rotary up-draft kiln. Forty-eight hours are required to burn the ware. Twelve cords of wood, mostly pine, are used to each kiln.

The principal vessels made are jugs, crocks, jars, and churns, which contain from 1 to 5 gallons each. The unglazed ware burns to a beautiful light buff color. Arkansas slip is used.

The clay used by this factory is obtained in two places. The purest and best clay comes from a pit on the roadside one-half mile south of the kiln, between the kiln and Benton. When fresh the clay has a chocolate color, but becomes white when dry. It is plastic, free from grit or sand, and very similar in appearance to the clay from Holly Springs, Miss. It occurs in large lenses and is overlain by Lafayette sands and gravel, which in places rest directly on the clay. In some places the stratified sands of the Tertiary intervene between the clay deposits and the Lafayette. The clay, therefore, belongs to the older Tertiary sands and not to the Lafayette. Leaf impressions in the clay are reported to be of frequent occurrence.

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The second locality from which clay is obtained is at the pottery. This is a dark-blue stratified clay containing more or less sand. An equal amount of clay from the two localities is used in making the ware.

Benton Brick Manufacturing Company.—Bricks are made by the Benton Brick Manufacturing Company from a surficial deposit that lies above the Lafayette gravel beds. It is a very sandy brick clay composed of about one-third clay and two-thirds sand. The clay is hauled from the pit to the pug mill in wheelbarrows. The pug mill is run by horse power. The bricks are molded in a hand mold and taken to a shed, where they are dried in air without artificial heat. When the bricks are sufficiently dried they are wheeled to a rotary up-draft kiln and burned. The plant employs eight men and has a capacity of 5,000 bricks a day. Five days and nights are required to burn the brick and 20 cords of wood are used to the kiln—10 cords of pine and 10 of oak. The clay makes bricks of poor quality.

SCOTT COUNTY.

GENERAL GEOLOGY.

The geology of Scott County is like the geology of those parts of Sebastian County that lie below the coal. The coal-bearing beds enter Scott County only through the parts occupied by the Poteau Mountains. So far as the clays alone are concerned, however, the coal is of but little importance, for there is an abundance of excellent clay shale in the rocks below the coal.

The rocks of Scott County are all more or less folded, and the denudation that has removed much of them has left the usual ridges of sandstone dominating the valleys cut in the shales.

In the northern part of the county there are long, winding sandstone ridges with shale valleys parallel to them. Coops Prairie, already mentioned under Sebastian County, is half in Scott County, Coops Ridge swinging around the east end of it. Bluff Ridge, starting a mile south of the eastern end of Coops Ridge, runs a little north of east for 4 miles, to the toll bridge, then turns northward for 2 miles, and then swings eastward, crosses Washburn Creek one-half mile above the point where that stream enters Petit Jean Creek, and thence continues eastward and southward until it goes nearly around Jennings Hill. Between Jennings Hill and Bluff Ridge there is another ridge of sandstone that completely encircles Jennings Hill, though it is twice cut by Petit Jean Creek.

These ridges of sandstone are mentioned only for the purpose of directing attention to the shale beds that accompany them, for the valleys between are made up for the most part of shales which are here argillaceous and there sandy. Washburn Creek, just north of Pine Log Ridge, in the extreme northern end of Scott County, flows along

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one of these shale valleys. East of the mouth of Washburn Creek this same shale valley continues past Barber post-office into Logan County. South of Pine Log Ridge another long but narrow valley crosses this end of the county. Still farther south is Bluff Ridge, already mentioned. The valley south and east of Bluff Ridge is a remarkable one. Geologically it begins on the headwaters of Little Petit Jean Creek, southwest of the toll bridge, passes northward by way of Crow post-office, then turns eastward to the mouth of Washburn Creek, extends down Petit Jean Creek to the point where it cuts through Bluff Ridge, and there swings southward and westward past the town of Belva. Here it forks, one part passing westward toward Crow, the other swinging southward and eastward, where it runs along the north base of the Poteau Mountains. Everywhere throughout this valley are shales, some of them clay shales and others more or less sandy. Another shale valley runs completely around Jennings Hill.

The Poteau Mountains themselves are made up of shales and sandstones that are higher in the geologic series than the rocks of the lower lands both north and south of them. Near the base of the southern slopes of Poteau Mountain there is a series of parallel ridges and valleys. These ridges are of sandstone again and the valleys between are in shales. Beginning at the Indian Territory line in sec. 31, T. 3 N., R. 32 W., one of these shale valleys passes just north of Gipson post-office and just north of the town of Cauthron, and so on eastward to the valley of Self Branch, 5 miles north of the town of Waldron. South of the Poteau River the region both north and south of Walker Mountain is made up of a series of sandstone ridges and shale valleys. The sandstones predominate here, however, and the shales do not form such thick beds as they do north of the Poteau Mountains or in the region about and south of Waldron.

The town of Waldron stands in a broad shale valley which passes 4 or 5 miles east of the town and then bends northward and westward and swings back so as to form one of the set of valleys parallel with Poteau Mountain along its south side. A mile south of Waldron is a sandstone ridge that extends a few miles farther west and bends northward, ending in a low, hooked ridge about 2 miles west of the town. East of Waldron this same ridge continues for several miles along the north side of the upper part of Poteau Creek. South of this sandstone ridge is a broad shale valley through which runs Haw Creek and the headwaters of Poteau Creek. South of this is a series of parallel ridges of sandstone, the most prominent of which are Piney Mountain and Ross Mountain. The shales interbedded with these sandstone beds are not very thick, but many of them are available for the manufacture of clay goods. One of the most prominent of these valleys is that along which Ross Creek flows. This is a shale valley about 11 miles in length.

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CLAY DEPOSITS.

Over the whole of the valley regions of Scott County ordinary brick clays occur in the form of loam or buckshot clays. In many places this brick loam is from 2 to 6 feet thick. It is often high in iron, however, and the brick made of the clays containing much iron are likely to be covered with dark brown or black spots, and the bricks as a whole usually have a dark color. These clays are especially abundant in the upper bottom lands of Poteau River, from the point where it enters Oklahoma up to and east of Waldron. They occur also along Black Fork of Poteau, along Ross Creek, and in the broader parts of the valley of Fourche La Fave River. North of Poteau Mountain similar clays are found in the upper bottoms of all the streams, but especially in those of Petit Jean Creek and its principal tributaries, and along Little Washburn Creek.

No establishments of any kind in Scott County are engaged in the manufacture of clay products.

SEBASTIAN COUNTY.

CLAY DEPOSITS.

CLASSES OF DEPOSITS.

So far as the actual development of the clay manufacturing interests are concerned Sebastian is one of the most important counties in the State. This development could not have taken place, of course, if the geology of the county had not been favorable to the building up of the clay industries; but the fact should not be overlooked that so far as geology alone is concerned several counties in the State are as well provided with valuable clays and clay shales as is Sebastian County.

The geologic structure of Sebastian County admits of clays and clay shales occurring (1) as shales in place in the uplands of all parts of the county; (2) as residuary clays in the uplands derived by disintegration from the Paleozoic shales; (3) as clays in the "second bottoms" or the elevated Pleistocene terraces that follow the general course of the river bottoms; (4) as clays in the alluvial deposits of the river bottoms.

SHALES.

The rocks of Sebastian County all belong to the Carboniferous, except the clays and alluvial deposits along the Arkansas River bottoms. There is but little variation in the older rocks of this county. They consist of sandstones, shales, fire clays, and coal. It has already been pointed out in the chapter on general geology that the sandstones and shales were originally deposited in water as horizontal beds of sediments, and that vegetation growing in marshes

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afterwards became coal. Subsequently all these beds have been pressed into folds, lifted into dry land, and in many places worn away.

The sandstones are in some places coarse enough to be considered grits or conglomerates, while the shales in places grade over through sandy shales to fine sandstones. The coal is confined to the upper portion of the Carboniferous rocks in Sebastian County, but the clay shales cover a larger area than the coal.

The sequence of the rocks varies from place to place owing partly to the fact that the folding and erosion of the beds has left one set of beds at the surface at one place and another set at another. Moreover, the horizontal variation of the beds or the grading of fine sediments into coarser ones results in a variation in the sequence of the beds, especially when the sections considered are several miles apart.

In the process of denudation (the weathering and breaking up of the rocks and their removal by streams) the shales decompose, readily forming clays, while the sandstones, as a rule, are more resistant. The result is that the valleys are usually cut in the shales, while the sandstones are left capping the hills if the beds are horizontal or forming long winding ridges if the beds are folded. In Sugar Loaf Mountain and in Jennings Mountain the beds are nearly horizontal, and these mountains are capped with sandstone, while in the long, narrow ridges, like Long Ridge, just north of Jenny Lind; Sand Ridge, running from Hackett City to Greenwood; Nigger Ridge, southwest of Huntington, and Devils Backbone Ridge and the other parallel ridges south of Greenwood, the resisting beds are sandstones that have been thrown into folds and then eroded. Inasmuch as the clay shales are interbedded with the sandstones the valleys curve with and follow the ridges, and it is in the valleys that the shales are usually found. At some places the shales are decomposed into soft, plastic pottery clays, as noted later, but more frequently they are compact, or fissile, breaking up under the influence of the weather into small, angular fragments.

One of the most important manufacturing interests of the State is based on the clay shales of the coal-bearing rocks of Sebastian County, which are used in the manufacture of paving bricks. This industry began under circumstances not without interest. In 1889 the citizens of Fort Smith had under consideration the paving of their streets, and the State geologist of Arkansas received a letter from Harry E. Kelley, the chairman of the paving committee, asking his advice in regard to the best clay of the region about Fort Smith for the manufacture of paving bricks. The State geologist visited Fort Smith and examined the clays and clay shales near that city. He found that attempts had been made to manufacture paving bricks from the sandy clays and loams of the river terraces, but these bricks were, of course, too soft to be available for paving streets. It was pointed out

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to the committee that the clay shales in the vicinity of the city were well adapted to the manufacture of paving bricks. This opinion was supported by analyses made by the State Geological Survey, and later by practical tests made by brick manufacturers.

The following letter was addressed to the paving committee after the examination:

DEAR SIR: At the request of the paving committee of your board of commerce I have made a cursory examination of the material in the immediate vicinity of Fort Smith with a view to ascertaining its availability for the manufacture of paving brick.

The clays and clay shales about Fort Smith available for the manufacture of bricks, tiles, pottery, etc., belong to two distinct geologic ages. To the newer division belong the yellowish, reddish, and dove-colored loams, clays, and sandy clays which underlie almost all the plain upon which the city of Fort Smith is built.

The bricks now made at Fort Smith are made either from the uppermost of these beds or from a mixture of this and the one just beneath it, as is now practiced at Pendle & Morrison's brickyards.

In some of the deeper hollows there are later deposits of chocolate-colored clay which by the admixture of organic matter has been changed to a deep black soil at the surface. An analysis of a similar clay from near Dardanelle is given below.

The other class of material which is available for the manufacture of pottery, bricks, tiles, etc., is a clay shale belonging to the Carboniferous series of rocks. These shales are interstratified with sandstones and other rocks of the coal measures and are probably widely distributed through Sebastian and adjoining counties. The clay said to have been taken from Crawford County to the brickyards of Pendle & Morrison for testing is simply a disintegrated clay shale. The light-colored and mottled clays overlying the sandstones of Harding & Boucher's quarry, a couple of miles south of Fort Smith, are also disintegrated clay shales. An extensive exposure of such shales, however, occurs much nearer the city. On the public road leading south from Fort Smith and about 600 feet south of the crest of what is popularly known as Nigger Hill the ditches beside the road have exposed a thickness of 10 or 15 feet of friable clay shales. This shale bed is capped by a stratum of sandstone, but its base is not exposed. It will be found to extend around the hills on both sides of the road, and there can be no question of its great abundance both at the locality mentioned and in the continuation of the bed around the sides of the hills.

Following is an analysis of the clay shale from Nigger Hill, in the vicinity of Fort Smith:

Analysis of clay shale from Nigger Hill.

[Specimen dried at 110°–115° C. Brackett & Smith, analysts.]

Silica (SiO_2)	58.43
Alumina (Al_2O_3)	22.50
Ferric oxide (Fe_2O_3)	8.36
Lime (CaO)	.32
Magnesia (MgO)	1.14
Potash (K_2O)	2.18
Soda (Na_2O)	1.03
Sulphur (S)	.16
Loss on ignition	6.87
	100.99
Sand in air-dried specimen	25.72
Water at 110°–115° C	3.37

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The clay shales spoken of as cropping south of the city would, of course, have to be ground before they could be used for the manufacture of either pottery or bricks, but in view of the nature of these clays, the ease with which they can be dug and ground, and the extent of the beds, it would seem very desirable that thorough practical tests should be made of this material and of its availability for making pottery, tiles, retorts, fire bricks, and paving bricks. It will doubtless be found necessary to mix with this material a certain proportion of the sandy clays so abundant all about Fort Smith, but a practical brickmaker can readily determine these proportions by a few trials.

I do not think there can be any doubt about the formations spoken of above furnishing excellent material for the manufacture of paving bricks, pottery, tiles, etc. * * *

Trusting that these clays and clay shales may receive from our citizens the attention to which they are justly entitled, I remain,

Very respectfully,

J. C. BRANNER, *State Geologist.*

The analyses showed the shales to be available for the manufacture of paving bricks, and practical tests bore out these results and predictions.

Samples of the shale were also sent for testing to the Brick and Terra Cotta Manufacturing Company, of St. Joseph, Mo., and the results obtained were favorable.

Specimens were also taken from the property of the Oak Park Land Company in the SE. ¼ NW. ¼ sec. 35, T. 9 N., R. 32 W., and shipped for testing to the Tennessee Brick Manufacturing Company, at Memphis. The following letters were received by Mr. May in regard to these tests:

MEMPHIS, TENN., *August 10, 1889.*

N. MAY, Esq.: In regard to the manner in which the bricks were made from the samples of Fort Smith clay or shale, will say: Each sample was separately pulverized, pugged, and molded by hand, the oldest and most crude method known for making bricks. With proper appliances for making and burning it would produce a brick not surpassed anywhere in the country for strength and durability and suitable for any purpose where the best bricks are required. It will admit of rapid drying without cracking.

Very truly, yours, HARRY MCCUE, *Superintendent.*

MEMPHIS, TENN., *August 13, 1889.*

Mr. NOEL MAY.

DEAR SIR: The tests that I have made of the new Fort Smith brick show very excellent results. The samples made of mixed clay are the best. The unmixed-clay samples are very good building brick, suitable for sewers and foundations, strong, dense, and heavy. They will be durable in any position.

The samples made of mixed clay, the two kinds being combined in about equal quantities, show remarkable strength and toughness. I made the percussion test on three samples and at the same time on one of the West Virginia brick, same as we used on North and East Court streets. The Fort Smith samples were fully equal, and I think rather superior, to the West Virginia, showing less abrasion and less granulation.

I hope you will continue your experiments in mixing varying quantities of the different clays until you have the strongest. Then you will have a superior paving brick.

Truly, yours, R. S. MILLER.

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By the month of November, 1889, W. A. Doyle was using the Nigger Hill clay shales at Fort Smith in the manufacture of paving bricks. The business succeeded from the outset, and there was soon built up at that place a large and prosperous business in the manufacture of paving and building bricks from the shales.

Two analyses are here given of the Fort Smith clay shales, and for purposes of comparison analyses of the well-known Carboniferous shales of Akron, Ohio, and of Cheltenham, Mo., are added.

Analyses of clay shales.

[Specimens dried at 110°-115° C. Brackett & Smith, analysts.]

	Fort Smith.		Akron, Ohio.	Cheltenham, Mo.
	Harding & Boucher's quarry.	W. A. Doyle's paving-brick kiln.		
Silica (SiO_2)	57.10	58.43	60.05	54.92
Alumina (Al_2O_3)	23.74	22.50	20.00	22.71
Iron (Fe_2O_3)	8.18	8.36	6.82	9.81
Lime (CaO)	.53	.32	.52	.52
Magnesia (MgO)	1.04	1.14	.45	2.59
Potash (K_2O)	1.53	2.18	1.79	3.16
Soda (Na_2O)	.87	1.03	1.60	.62
Sulphur (S)	.....	.16	1.95	.....
Loss on ignition	7.21	6.87	6.96	5.88
	100.20	100.99	100.14	100.21
Sand	.12	25.72	29.12	2.04
Water at 110°-115° C	4.24	3.37	1.25	2.69

These Carboniferous shales outcrop at many places in the vicinity of Fort Smith and, indeed, in all parts of Sebastian County.[a] They are exposed at W. A. Doyle's paving-brick factory between Towson and Wheeler avenues, Fort Smith; at Harding & Boucher's quarry in the northeast corner of the SW. ¼ sec. 28, T. 8 N., R. 32 W.; and immediately across the Texas road from Harding & Boucher's quarry, on the railway track running through the SE. ¼ sec. 20 and the NE. ¼ SE. ¼ sec. 29 of the same township and range. They are also seen in a railway cut on the lands of the Oak Park Company in the SE. ¼ NE. ¼ sec. 35, T. 9 N., R. 32 W. At all these places the shales have disintegrated and formed a clay. A well on the Adams lot, in the NE. ¼ SW. ¼ sec. 15, T. 8 N., R. 32 W., shows a section of this clay 10 feet thick. At Harding & Boucher's quarry the clay formed from the disintegrated shale has a thickness of 6 feet, and in the railway cut through secs. 20 and 29 a thickness of 3 feet is visible. The analysis of the Harding & Boucher shales is given above.

There are exposures also in the banks of a small stream near Nowland's spring, in the NE. ¼ NE. ¼ sec. 34, T. 9 N., R. 32 W. In the SW. ¼ NE. ¼ sec. 9, T. 8 N., R. 31 W., near the center of the section, and in the SW. ¼ SW. ¼ sec. 7, T. 7 N., R. 31 W., and in a cutting on the Little Rock road in the SW. ¼ SE. ¼ sec. 15, T. 8 N., R. 32 W., similar shales are exposed. In these sections the shales are overlain

[a] The notes on the occurrence of shales about Fort Smith are by William Kennedy.

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by grayish-brown sandstone, and retain their shaly character in a greater or less degree according to the protection given to them by the overlying sandstone.

In the section at Nowland's spring the bluff is protected by a covering of grayish-brown sandstone about 4 feet thick. The shales immediately under the sandstone are black, hard, and somewhat arenaceous. Thin beds of iron-stained quartz run throughout the upper 10 feet of the shales. Below, where they are exposed to the action of the waters of the stream, the shales form a soft, blue clay-like material. These blue shales are about 4 feet thick and overlie a series of soft black shales.

In the bluff overlooking Arkansas River in the SW. ¼ NE. ¼ sec. 19, T. 8 N., R. 31 W., near the center of the section, the covering is a heavy bed of brownish sandstone 7 feet thick. The shales beneath are light yellow for 5 feet immediately below the sandstone, and 3 feet of soft black shales are exposed below the yellow.

The quantity of talus along the bluff is so great that the shales are almost everywhere covered up. In the section shown at the end of the bluff in sec. 19 the sandstone projects about 7 feet beyond the underlying shales.

The following is a section at the end of the bluff in the SW. ¼ NW. ¼ sec. 19, T. 8 N., R. 31 W.:

Section in bluff of Arkansas River.

	Feet.
Brownish, heavily bedded sandstone	7
Soft, friable, yellowish shale, with whitish streaks in the upper division	5
Black shale somewhat harder than the yellow, and containing some red streaks	3
Talus covering black shales to the level of the river	150

A section in the SW. ¼ SW. ¼ sec. 7, T. 7 N., R. 31 W., gives the following:

Section in SW. ¼ SW. ¼ sec. 7, T. 7 N., R. 31 W.

	Feet.
Sandstones	7
Yellow shales, soft where exposed and forming dark yellow clay	4
Black shales	10
Sandstones	5
Blue shales	70
Black shales.	

The black shales lying at the base of the bluffs in sec. 19, T. 8 N., R. 31 W., and in secs. 24, 26, 34, 35, 27, and 28, T. 8 N., R. 32 W., on the north side of Massard Prairie, and in sec. 6, T. 7 N., R. 31 W., on the southeast side of the prairie, are the same beds, and they pass under Massard Prairie in an almost horizontal position. These shales are also seen at a few places where Massard Creek and one or two smaller streams have cut down through the overlying yellow prairie soil.

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Wherever the shales are exposed they rapidly disintegrate and form a stiff clay, having approximately the colors of the shales from which the clay has been formed.

The following is a section at Doyle's paving-brick factory:

Section at Doyle's paving-brick factory.

	Feet.
Red sandy clay containing waterworn pebbles in considerable quantities	2
Blue and black shales interstratified and inclosing some thin beds of red arenaceous shale	25
Sandstone at the base.	

In this section the gravel and clay overlying the shales have partially obstructed the work of disintegration, so that the shales have not yet completely disintegrated. The softer blue shales have for the most part disappeared in the clay, but the harder black and red shales still remain in their shaly form, although somewhat soft and easily crushed.

Wherever the shales have been exposed by the removal of the overlying sandstones and gravel they readily lose their shaly character and assume the condition of a plastic clay, having the color and position in the series of the shales from which they are derived.

At Harding & Boucher's quarry, 1½ miles south of Fort Smith, in the northwest corner of the SW. ¼ sec. 28, T. 8 N., R. 32 W., the surface material consists of about 6 feet of disintegrated shales, which rests on the sandstone of the quarry. These shales have disintegrated and formed a gray mottled clay. In the lower part of the bed the disintegration is not always complete and fragments of shale are scattered through the clay. Analyses of these clays and shales are given below.

The shales exposed along the Missouri Pacific Railway track through the SE. ¼ sec. 20, T. 8 N., R. 32 W., are in the same disintegrated and clayey condition as those seen higher up the hill at Harding & Boucher's quarry.

Analyses of argillaceous shales from Fort Smith.

[Specimen dried at 110°–115° C. Brackett & Smith, analysts.]

	Nigger Hill.	Harding & Boucher's quarry.		
	1.	2.	3.	4.
Silica (SiO_2)	58.43	57.10	65.12	42.12
Alumina (Al_2O_3)	22.50	23.74	19.05	18.84
Ferric oxide (Fe_2O_3)	8.36	8.18	7.66	26.35
Lime (CaO)	.32	.53	.34	.28
Magnesia (MgO)	1.14	1.04	.31	.74
Potash (K_2O)	2.18	1.53	1.23	1.10
Soda (Na_2O)	1.03	.87	.85	1.85
Sulphur (S)	.16	.....	.....	.....
Loss on ignition (water)	6.87	7.21	6.12	8.77
	100.99	100.20	100.68	100.05
Sand in air-dry specimen	25.72	76.40	21.88	None.
Water at 110°–112° C	3.37	4.24	4.79	3.19

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The Nigger Hill shale is from the paving-brick kiln of W. A. Doyle, on Towson road, Fort Smith; the other three are from Harding & Boucher's quarry in the northwest corner of the NW. ¼ sec. 28, T. 8 N., R. 32 W. Sample 2 is from the gray clay about 3 feet below the surface; sample 3 is from the yellow mottled with red; and sample 4 is from the undecomposed shale next to the sandstone beneath.

It is not possible to specify all the places at which clay shales available for the manufacture of bricks, sewer pipe, and similar products may be found in Sebastian County. They are associated with the coal at many places in the coal mines. Many of the clays that lie immediately beneath the coal are available as fire clays.

A specimen of gray clay from KcKenna's quarry, near Hackett City, was sent in by Mr. Ed. McKenna. The analysis is given below.

Analysis of gray clay from McKenna's quarry, at Hackett City.

[Material dried at 110°–115° C. R. N. Brackett, analyst.]

Silica (SiO_2)	54.13
Alumina (Al_2O_3)	30.69
Ferric oxide (Fe_2O_3)	3.15
Manganese oxide (MnO)	Trace.
Lime (CaO)	.63
Magnesia (MgO)	.94
Potash (K_2O)	.49
Soda (Na_2O)	2.01
Loss on ignition	8.54
	100.58
Water at 110°–115° C	4.82

At the Hartshorn coal mine, 4 miles south of Fort Smith, is a bed of dark-gray shale 4 feet thick. A sample was sent to the Survey by Mr. W. A. Doyle, of Fort Smith, and analyzed, with the results given below. The relation of this shale to the coal at the mine is not stated.

Analysis of shale from the Hartshorn coal mine.

[Material dried at 110°–115° C. R. N. Brackett, analyst.]

Silica (SiO_2)	70.83
Alumina (Al_2O_3)	17.49
Ferric oxide (Fe_2O_3)	3.64
Magnesia (MgO)	.91
Potash (K_2O)	.25
Soda (Na_2O)	1.72
Loss on ignition	4.95
	99.79
Water at 110°–151° C	.76

The region about Mansfield may be taken as a type of the topography and geology of most of the country south of Fort Smith. The

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accompanying section (fig. 17), by Professor Purdue, shows the general character of the geology and the relation to each other of the shales and sandstones of the region. There are long parallel ridges of sandstone with shale valleys between. The shales are at some places so interbedded with sandstones that they are hardly available for manufacturing purposes on a large scale, but for the most part they form beds of enormous thickness and of a composition suitable for making paving bricks, sewer pipe, and fire-clay goods. Just north of Mansfield the heavily shaded area in the section represents the clay shales used by the Choctaw Pressed Brick and Terra Cotta Company.

One-half mile south of the town an almost unbroken ridge, known as Coops Ridge, incloses a small circular valley. The ridge is made up of sandstones that dip southward on the south side and northward on the north side; in other words, Coops Ridge surrounds a small anticlinal valley, called Coops Prairie. Inside of this valley are thick beds of clay shales that are probably available for the manufacture of various kinds of clay goods. The valley between Coops Ridge and the town of Mansfield is more than a quarter of a mile

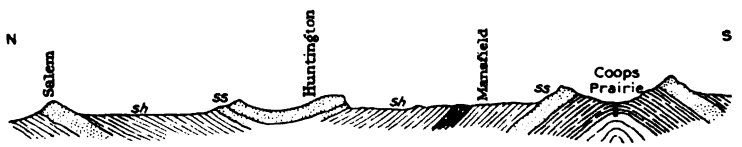

FIG. 17.—North-south section showing structure and relative positions of the shales and sandstones from Coops Ridge to Salem. *sh*, Shale; *ss*, sandstone.

wide and is cut in shales that extend westward to Cherokee Prairie and then swing back eastward around the south side of Coops Ridge and form the broad, open valley that lies about the village of Fuller, in Scott County, and extends a mile east of it, and then swing westward again and around to Mansfield. North of Black Jack Ridge is another shale valley not more than a quarter of a mile wide that extends from James Fork, 4½ miles west of Mansfield, northeastward past Mansfield 4 miles, and swings westward past the town of Dayton, which stands in the shale valley. Another shale valley parallel in the main with the last one mentioned begins a mile south of Liverpool post-office and runs northeastward parallel to and just south of Nigger Ridge, crossing Cherokee Creek a mile south of the town of Huntington, and about 2½ miles farther east it swings northward and then westward about 4 miles, when it turns due northward and extends for 5 miles or more along the east base of Devils Backbone Ridge. This same bed of shale can be traced for many miles along the base of this ridge past Burnsville post-office into the eastern edge of Sebastian County.

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This description is doubtless sufficient to show that the clay shales of Sebastian County are widespread over the entire county, and that the beds are of great thickness. The value or availability of each bed has not been determined, but such tests can be made practically whenever it becomes necessary to consider the location of a manufacturing plant, and a brief examination of the geology should show the distribution of the materials.

POTTERY CLAYS.

It has already been pointed out that the shales of this region break up or decompose under the influence of the weather, forming plastic clays. Such clays are available for the manufacture of paving bricks and sewer pipe, or for pottery. Clays thus formed are about the only ones used for the manufacture of pottery in the upland regions of Sebastian County.

The only pottery clay that was used in Sebastian County in 1889 came from the S. ½ SE. ¼ sec. 27, T. 7 N., R. 30 W. An examination of the geologic structure of the region in which it is found affords evidence of its origin and suggests where other and similar clays may be found in this county.

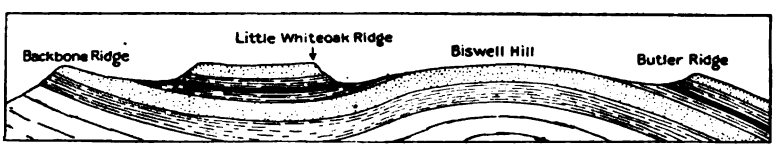

FIG. 18.—North-south section through Biswell Hill.

The place at which this clay occurs is at the north base of Little White Oak Ridge. This ridge runs southwestward toward Greenwood and northeastward past Auburn post-office, where it curves westward, merges into Butlers Ridge, runs northwestward and ends at Butlers Knob, in sec. 10 of this same township and range. To the west of Biswell Hill it appears again, striking away to the west and southwest, where it is known as Tennessee Ridge. The rocks of this line of ridges dip away from Biswell Hill on all sides, and a north-south section through Comby's clay pits would expose the rocks as they are shown in the section below.

A section across Little White Oak Mountain, Biswell Hill, and Tennessee Ridge would display practically the same structure as that shown above. This structure explains the origin of the Comby clays and suggests at the same time that similar clays may extend along the northwest side of Little White Oak Ridge, the southwest side of Butlers Ridge, and the south side of Tennessee Ridge.

The example cited above is given for the purpose of illustrating the general features of the geologic structure of Sebastian County and

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to show the origin of the residuary pottery clays rather than to explain the presence of clay at a single locality. Throughout the entire county the rocks are thrown into folds and eroded, and wherever the argillaceous shales are exposed to decomposing agencies they have been changed into plastic clays.

In searching for the clays, or the clay shales from which they are derived, one must keep in mind the structural features of the region and the agencies by which the clays are produced and modified. It should not be forgotten, however, that sedimentary rocks frequently change in character in passing along the outcrops, so that what is a sandstone at one place may be an arenaceous shale at another and an argillaceous shale at a third locality.

The upland clays of Sebastian County are confined to the region of Paleozoic rocks. These clays, however, are not all produced by decomposition directly from the argillaceous shales. Some of them have been washed into the valleys and, mingled with the residual rocks of the region, have formed "buckshot clays" by precipitation within them of the iron carried in solution by percolating waters. The method by which these clays are formed is described in Chapter II of this report. These "buckshot clays" are not available for the manufacture of pottery, but they are used more or less for making bricks.

COMBY'S CLAYS.

The clay formerly used at Comby's pottery is a light-yellowish surface clay, found in a low-lying piece of ground in the S. ½ SE. ¼ sec. 27, T. 7 N., R. 30 W., where it has a depth of about 2½ feet. The mode of origin of this clay has already been described.

Analysis of Comby's pottery clay.

[Brackett & Smith, analysts.]

Silica (SiO_2)	81.61
Alumina (Al_2O_3)	10.52
Iron (ferric) oxide (Fe_2O_3)	2.70
Lime (CaO)	.32
Magnesia (MgO)	.40
Potash (K_2O)	.66
Soda (Na_2O)	.57
Manganese (MnO)	Trace.
Water (H_2O)	3.95
	100.73
Water at 110°–115° C.	3.86
Fine sand	18.43

The ware from this clay is of poor quality and consists chiefly of such articles as are in local demand, such as churns, jugs, crocks, and jars. No other kinds of ware have been manufactured. It can not be said that this clay has been so tested as to establish or disprove its availability for the manufacture of pottery.

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Close to the kiln and on the same quarter section there is a small deposit of stiff light-blue clay which has been turned for pottery, but without success. When this blue clay was used alone the ware made from it cracked in drying. A mixture of this and a pale-blue, almost white, sandy clay from the NE. ¼ NE. ¼ sec. 7, T. 6 N., R. 30 W., has also been tried with some success. The results, however, were not altogether satisfactory and the work was abandoned.

The pale-blue sandy clay from sec. 7, T. 6 N., R. 30 W., outcrops at several places along the side of a small hill and in the bottom and banks of a small stream that crosses the wagon road leading from Greenwood to Charleston. Mr. Comby tried this clay alone for the manufacture of pottery, but with the appliances at command he did not succeed. When mixed with the surface clay from the SE. ¼ SE. ¼ sec. 27, T. 7 N., R. 30 W., the results were fairly successful.

GLAZING MATERIAL.

Mr. Comby tried a black silt found on the bottom lands at the mouth of Vache Grasse Creek for glazing purposes. It is said to have served the purpose of a slip, but not much reliance can be placed upon the experiment. Analyses of this river deposit and of the Albany slip have been made by the Arkansas Geological Survey.

Analysis of Vache Grasse and Albany slip.

[Brackett & Smith, analysts.]

	Vache Grasse slip.	Albany slip.
Silica (SiO_2)	70.95	58.05
Alumina (Al_2O_3)	12.24	14.86
Iron (ferric) oxide (Fe_2O_3)	4.73	6.76
Lime (CaO)	1.90	6.61
Magnesia (MgO)	.97	3.08
Potash (K_2O)	1.14	1.18
Soda (Na_2O)	.66	.80
Water (H_2O)	7.01	7.41
	99.60	98.75

PRAIRIE CLAYS.

Over the whole of the upland portion of Sebastian County the soils are derived by decomposition from the rocks. The materials are shifted somewhat—washed down from the slopes and spread over the valleys—and are afterward more or less leached and altered by secular weathering. This process produces what are popularly known as "buckshot clays" of the prairies and slashes. These clays are not specifically mentioned as characteristic of this county, but as they are derived chiefly from the shales they are mentioned under this general head.

The whole of sec. 3, the greater part of sec. 2, the SE. ¼ sec. 4, the NE. ¼ NE. ¼ sec. 10, and the NW. ¼ sec. 11, T. 8 N., R. 32 W., are

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covered with a yellowish buckshot clay, or prairie soil, containing considerable quantities of iron nodules about the size of a pea. The section in the banks of a small stream running through sec. 3 shows a thickness of about 3 feet of this clay.

In sec. 4 of the same township and range a similar yellow loam overlies a deposit of dark-red clay. In the W. ½ NW. ¼ sec. 35, T. 9 N., R. 32 W., a band of chocolate clay about 4 feet thick lies between the two yellow divisions of the exposed clays. The chocolate clay forms the surface for some distance and then passes under a heavy bed of yellow clay.

The surface soil of Massard Prairie is a yellow clay or prairie soil, having a general thickness of about 4 feet. This clay rests on the dark-blue or black shale which is seen at the base of the different sections exposed in the bluffs on the north and south sides of the prairie. A section from the bank of a small creek in the SW. ¼ SE. ¼ sec. 1, T. 7 N., R. 32 W., may be taken as a representative section of this prairie.

Section in SW. ¼ SE. ¼ sec. 1, T. 7 N., R. 32 W.

	Feet.
Thin covering of humus at surface.	
Yellow (almost orange-colored) clay containing nodules of iron in its lower division	4
Black or dark-blue shales, broken into kidney-shaped pieces at base.	

Where the soil has been washed off the surface the ground is covered with the nodules of iron in the shape of gravel.

In the NE. ¼ SE. ¼ sec. 19, T. 8 N., R. 31 W., the surface soil is red clay, and in the S. ½ sec. 29, on the south side of Massard Creek, a yellow clay overlies the coal in some of the openings.

In the NW. ¼ SW. ¼ sec. 29, T. 8 N., R. 31 W., near Massard post-office, a dark-red clay covers the small hill lying to the southeast of the prairie.

Nothing has ever been done to demonstrate the usefulness of these clays for any purpose. There is little doubt, however, that many of them might be profitably used for the manufacture of ordinary building bricks, and for this purpose the clays found on Massard Prairie and on the prairie-like district of secs. 2, 3, 4, and 10, T. 8 N., R. 32 W., will probably be much better adapted for making a hard, solid brick than the red earth found close to Fort Smith and used at present. It may be safely said that these clays will, with proper treatment, make as good and as strong a brick as can be found anywhere else throughout the valley of Arkansas River.

TERRACE CLAYS.

Over the lowlands near Arkansas River, in some places extending back inland for several miles, generally in the form of terraces, there is a system of unconsolidated deposits which are probably of Pleisto-

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cene age. The material forming these terraces are yellowish, reddish, and lead-colored loams, clays, sands, and gravels. They lie in horizontal beds, but have been cut and more or less mutilated by erosion over the whole surface and by streams that cross them to enter Arkansas River. These Pleistocene deposits cover most of the plain on which the city of Fort Smith stands, and the peninsula extending northeastward toward Van Buren, where fragments of them occur here and there along the river east of Fort Smith. The clays of this series are exposed in what may be regarded as a typical section along the railway near the Ketcham iron works and at other points south of the city. The uppermost bed is a yellowish clay, in some places more or less mottled and in others containing small, friable nodules of iron. Although its characteristic color is yellow, this bed is in some places ashen gray and in others bright red.

In the typical section just mentioned the next bed below the yellow clay loam is a dark-red clay which contains a good deal of sand and which is about 10 feet thick. Below it is a bed about 1 foot thick of deep-red to chocolate-colored clay, and below lies a bed of fine sand. The bottom of the sand is not exposed. The thickness and quality of these beds varies greatly; the yellow loam is entirely wanting in many places, having been removed by erosion, while the red clay may contain occasional beds of sand.

It can not be positively stated that pottery clays do or do not exist in these Pleistocene river terraces, but the nature of the beds seen is favorable to the occurrence in them of pockets of pottery clays. In these terraces or second bottoms extensive deposits of brick earth are found, both in Sebastian and in adjoining counties.

RECENT ALLUVIUM.

The Pleistocene terraces referred to above are distinct from the river-bottom silts. The latter stand at a lower level and are usually less brilliantly colored. No pottery clays are now known in the bottom, but it is possible that they may occur there. As a rule the alluvial deposits are silts and sands rather than clays, and such pottery clays as they contain will probably be found only in pockets.

CLAY INDUSTRY.

UTILIZATION OF THE CLAY SHALES.[a]

Although the clay shales of Fort Smith and of Sebastian County are suitable for the manufacture of sewer pipe, fire bricks, and pottery, nothing has been done thus far to utilize these shales for making such articles. The abundance of excellent raw materials, the proximity of the deposits to the coal fields, and the possibility of building

[a] The notes on the brick industries of Fort Smith are chiefly by William Kennedy.

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up a larger trade in clay products in the South and Southwest ought to lead to the early development of such industries at some point in Sebastian County.

Chemical analyses of the argillaceous shales show them to be clays so far as their chemical composition is concerned. They have been changed, however, by pressure and time in physical appearance and character. The chemical composition of these clay shales of Sebastian and adjoining counties suggests the possibility of using them, when ground and washed, for the manufacture of the common grades of pottery. The clay shales have the average composition shown in the table below. For the purpose of comparing this with the pottery clays of the Tertiary region of the State (Benton, Perla switch, etc.) the average composition of the latter is given in an adjoining column.

Analyses of clay shales and of Tertiary pottery clays.

	Clay shales.	Tertiary pottery clays.
Silica (SiO_2)	58.91	68.20
Alumina (Al_2O_3)	22.21	21.79
Iron (ferric) oxide (Fe_2O_3)	7.64	1.77
Lime (CaO)	.53	.20
Magnesia (MgO)	1.37	.....
Potash (K_2O)	2.15	1.12
Soda (Na_2O)	.93	1.16
Water (H_2O)	6.64	6.44

The clay shales contain a somewhat higher percentage of the bases (iron, lime, magnesia, potash, and soda), elements which increase the fusibility of the material, and a lower percentage of silica. The higher percentage of iron in the clay shales would give the pottery made from it a dark color like that of sewer pipe, but this objection would not apply seriously to jugs and many other articles. The upper weathered portions of the beds can be ground more readily, while the already decomposed and plastic clays that usually cover the exposed surfaces of these shale beds may advantageously be mixed with the crude material.

BRICK PLANTS.

Paving bricks.—It is only since 1889 that the manufacture of paving brick has been carried on at Fort Smith. Mr. W. A. Doyle had the first contract for the paving of Garrison avenue, and 3,000,000 bricks were required for this purpose. The bricks were made from the disintegrated shales found on Towson road between Towson and Wheeler avenues. The shales were ground before pugging. For this purpose a Penfield crusher was used. The clay was then pugged in a No. 10 D pug mill, and the bricks were made in a No. 20 B Penfield machine having a daily capacity of 50,000 bricks. The machinery was driven by steam power. The bricks were end cut and dried in a

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steam heated drying shed and burned in the ordinary open kiln. The fuel used was a mixture of coal and wood.

In drying these bricks part with their water very slowly, and it usually requires about six days to dry them sufficiently to be put in the kiln. The time allowed for burning is from ten to twelve days. When burned hard the outside bricks are dark brown and the inside bricks dark blue. In the kiln used at Fort Smith the outside bricks were bright red.

Clays formed by the disintegration of these shales shrink considerably in drying and burning. The bricks made at Fort Smith shrink about 1½ inches in the length of the brick (9½ inches), and the average settling of a kiln 36 bricks high is about 2 feet.

In setting the kiln it is necessary to set the rows close to one another in order to provide for the widening of the spaces between the rows of bricks due to the shrinkage.

There are at present three brick plants in Sebastian County. Two of these are in Fort Smith and the other at Mansfield.

The Choctaw Brick and Gas Company.—A plant was established in 1901 at Mansfield, in the southeastern part of the county, by the Choctaw Brick and Gas Company. Common building bricks are made from Carboniferous shale. The shale is pugged and molded in the Berg machine. The bricks are dried in sheds and nine to ten days are required to dry them sufficiently to place in the kiln. They are burned in up-draft and down-draft kilns, which hold from 50,000 to 250,000 bricks each. Five kilns are in use. The kilns are arranged to use coal and natural gas for burning, and about one-half ton of coal is consumed for each 1,000 bricks. The length of time for burning a kiln is about fifteen days. The shrinkage of the clay is about one-sixteenth. The output of the plant is 20,000 a day.

Plants at Fort Smith.—The two plants located at Fort Smith are the Fort Smith Paving Brick and Fire Clay Company, Louis Ismay & Brother, lessees, and a plant operated by John D. Carbaugh. Detailed information concerning these plants was not obtained.

The material used in the manufacture of the ordinary red building brick at Fort Smith occupies a district west of the city that includes the greater portions of secs. 9 and 16, the whole of fractional secs. 8 and 17, and the northwestern portion of sec. 20, as well as the SW. ¼ sec. 4, all in T. 8 N., R. 32 W. The SW. ¼ SE. ¼ sec. 34, T. 9 N., R. 32 W., also contains a red earthy clay from which bricks have been manufactured.

This brick earth is a stiff clay which is in places mixed with so much sand that the beds have the appearance of homogeneous deposits of sandy clay. It is, however, very irregular in its texture, varying within short distances from stiff clay to loose sand. Both sand and clay are of a red color, dark red when wet and pale yel-

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lowish brown when dry and exposed for any great length of time. At Messrs. Bocquin & Reutzel's old location on the strip of land lying between Towson road and Wheeler avenue, Fort Smith, on the west side of the SE. ¼ sec. 17, T. 8 N., R. 32 W., the clay has a pale-yellowish, almost gray, color.

The average thickness of this mixed clay and sand varies considerably, but averages about 6 feet. A section taken close to the line between Oklahoma and Arkansas, near the bank of Poteau River, gives the following section:

Section near Poteau River.

	Feet.
Reddish-gray sand	2
Red clay	3–6
Red sand	6–8

The bottom of the red sand is not reached in this exposure.

In the district between Arkansas River and Poteau River, along Fourth street in Fort Smith, the red sand and clay have been penetrated to a depth of 12 feet. The sand and clay seem to be overlain by a course white river sand. In this district the clay also becomes much more sandy.

Bricks made from the brownish-yellow sandy material are soft and will not bear much rough handling. They are readily injured by rain and ought to be dried under cover. In the kiln they will not stand a heat sufficiently high to make hard bricks without fusing. It is no uncommon thing for the arches to fall in, and when the kiln is opened the bricks forming the broken arches are found to be a fused mass of half-burned clay and dark-greenish slag. The result of this tendency to fuse is that the bricks must be burned soft and will not bear rough handling or resist the crushing strain imposed on bricks used in the erection of heavy structures. The loss through breakage in handling is also considerable, amounting in most yards to 15 or 20 per cent. When burned these bricks have a bright-red color, and when re-pressed for front or face bricks they are darker and have smooth faces and square corners. The color of bricks of this class is uniform and good.

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The following analyses of this clay dried at 110°–115° C. show its composition:

Analyses of clay from Fort Smith.

[Brackett & Smith, analysts.]

	1.	2.	3.	4.	5.
Silica (SiO_2)	83.83	84.00	74.79	76.26	76.20
Alumina (Al_2O_3)	9.32	8.33	12.86	11.74	12.41
Ferric oxide (Fe_2O_3)	2.64	2.73	4.90	4.54	4.36
Lime (CaO)	.34	.27	.38	.39	.49
Magnesia (MgO)	.45	.35	.90	.79	.54
Potash (K_2O)	1.27	.83	1.73	1.28	1.21
Soda (Na_2O)	.85	.82	1.49	.98	.84
Loss on ignition (water)	2.40	2.81	2.91	3.82	3.75
	101.10	100.14	99.96	99.80	99.80
Fine sand	38.23	37.57	29.77	47.79	11.89
Water lost at 110°–115° C.	2.21	2.45	2.76	3.71	4.06

No. 1 is the lighter colored clay from the bank opposite Ketchum Iron Company's shop; No. 2 is the yellow clay overlying No. 3 at the Ketchum Iron Company's shop; No. 3 is the lower reddish clay at Ketchum Iron Company's shop (underlying No. 2); No. 4 is the red sandy clay from Messrs. Pendell & Morrison's old brickyard; No. 5 is an ashen-gray clay from the south end of the Fort Smith and Dardanelle Railway.

POTTERIES.

Comby's pottery.[a]—This pottery was situated in the SE. ¼ SW. ¼ sec. 28, T. 7 N., R. 30 W. The kiln was a small one, built of stone cemented with clay, and was half underground—the kind of kiln sometimes called "groundhog." It was not adapted to salt glazing, and the Albany slip or black glaze was used. Sometimes a little salt was thrown into the kiln, but it affected only the ware at the front of the kiln next the fire, and that not always beneficially. There was nothing to protect the ware from the ashes of the fire, and every time a fresh supply of fuel was added or the fire touched the lighter ashes were sent in a shower among the hot ware, to settle down on the articles in the process of burning to become fixed to them by the glaze. The result of this is that the ware, especially that portion of it next the fire, presents anything but a pleasing appearance. With such a method of firing, a good class of pottery could not be made even with the best of pottery clays. The poor results obtained at this pottery must be attributed for the most part to the methods employed in burning the ware, though it is in part evidently due to poor raw material or to the improper treatment of the clay.

[a] The notes and statistics of Comby's pottery were collected by Mr. Kennedy. The plant has gone out of business.

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Caldwell's pottery.—A small deposit of bluish-white sandy clay mottled with red is found on the north side of a small creek in the SE. ¼ SE. ¼ sec. 10, T. 6 N., R. 31 W. This was at one time used to supply a pottery at Greenwood owned by Mr. Caldwell, but clay from this place has not been used for a number of years.

UNION COUNTY.

GENERAL GEOLOGY.

The strata underlying Union County consist almost exclusively of soft uncompacted clays, sand, brown coals (or lignites), and gravels of Tertiary age. The horizontality of these beds makes the geology comparatively simple. The clays are of various colors, exhibiting all the shades of brown, yellow, red, and gray. The highest beds of the county are those that cap the divide on which Eldorado stands. These beds are sandy clays and clayey sands, covered here and there by gravels of novaculite and quartz. From this elevated divide the surface of the county slopes away on all sides, the streams cutting deeper and deeper into the soft horizontal rocks. Along their banks, where bold headlands are left in the process of stream erosion, the stratification of the Tertiary beds is occasionally well exhibited. The best exposures, however, are in the river bluffs along the Ouachita at places where the river hugs the foot of the bluff closely, as at Camden, Newport Landing, Millers Bluff, Wilmington Landing, and New London. At Wilmington Landing the section exposed is typical of the geology of the entire highland region of the county.

The beds there exposed continue with some variation toward the west and underlie a large part of Union County, and in all probability underlie Columbia County also. In the deeper channels of the larger streams the beds of soft rocks are penetrated to greater depths and the entire section given on page 220 is exposed here and there, though generally only in fragments.

Where erosion has not been so powerful and so concentrated as in the immediate neighborhood of Ouachita River the stream channels are broader and their sides less abrupt, so that the clays and other beds have thinner coverings along the side valleys that extend inland from the river.

The lignites of Union County are of the same kind as those of Ouachita County. Aside from any direct use to which the coal may be applied, it serves as a guide in searching for clays, for the clays are at many places associated with the lignite, either overlying or underlying it. Persons acquainted with the geology of this county report that at many places a bed of clay 15 feet thick overlies the lignite. The clay beds at Wilmington Landing and at

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New London Landing, on Ouachita River, overlie the lignite exposed in the river bluff at those places. This clay, however, is not everywhere valuable.

CLAY DEPOSITS.

In the neighborhood of Beach Creek, where it is crossed by the Mount Holly-Lisbon road, many small fragments of fine potter's clay are scattered through the sandy clays. These fragments are of no value in themselves, but their presence suggests the probability that they were derived from deposits of fine potter's clays in this neighborhood. Similar evidence of the presence of good clays are common at many points in both Union and Columbia counties. About Lisbon such clays are exposed in deep gullies, especially on the west side of the town, near Camp Creek, and also on Holmes Creek.

About 2 miles west of Lisbon, on the Lisbon-Mount Holly road, just west of the Rose farm, on the brow of a westward-sloping hill, 3 or 4 feet of dove-colored potter's clay is exposed by the roadside. The total depth of the bed, however, is not visible. In places this bed contains very thin laminæ of fine sand, which may prove injurious.

East of Lisbon the clays and sands are thinly laminated and interstratified, so that they are not available for the manufacture of pottery or fire-clay products.

Four miles west of Eldorado, on the road to Lisbon, there are some rather promising looking exposures, but so far as examined they contain too many streaks of sand to be useful. Further search in the vicinity is likely to discover good beds.

One and one-fifth miles west of Eldorado, on the Lisbon road, on the side of a hill facing westward, the following section is exposed:

Section near Eldorado.

	Ft.	in.
Yellow soil and clay at surface.		
Good pink clay with fossil leaves	1	
Gray, rather sandy potter's clay	4	
Pink sandy clay		8
Dull pink sands exposed	2	

The clays exposed by the Eldorado-Lisbon road, about 400 feet west of the first milepost west of Eldorado, are all or nearly all too sandy to be available for the manufacture of pottery.

Three miles east of Eldorado the road to Wilmington Landing passes over a bed of pink potter's clay containing abundant leaf impressions. On the south side of the road the bed is about 4 feet thick, but it is not exposed on the north side of the road.

About 1¼ miles southwest of Wilmington Landing, on the edge of the flat woods, some fair pottery clays are exposed by the roadside, but their thickness is not evident.

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There are said to be some very fine clays on Lapile Creek in T. 18 S., R. 13 W., probably in sec. 9 or 10.

At Wilmington Landing the Tertiary beds are well exposed in the river bluff and in the gullies that furrow its sides.

Section of river bluff at Wilmington Landing.

	Feet.
1. Sand on hilltop	2
2. Sandy clay	5
3. Light-gray clay	2
4. Pinkish clay	3
5. White sand with some clay	9
6. Fat buff clay with some sandy patches and lignite	16
7. Tough, somewhat sandy, light-colored clay	7
8. Fat gray clay	6
9. White sand	3
10. Outcrop of brown coal	3
11. Fat dove-colored clay	3
12. Sands with clay laminæ	5
13. Pink sandy clays with fossil leaves	6
14. Sandy clays and sands	10
15. Concealed to the level of Ouachita River	10
	90

The hills one-eighth of a mile south of Wilmington Landing continue upward the section given above. It is approximately as follows:

Section south of Wilmington Landing.

Clays and clayey sands at the surface.	Feet.
Lead-colored and pink pottery clays	12
Sands	6
Chocolate-colored sandy pottery clays	4
Lignite	3

The horizontality of the Tertiary beds of the region and the outcrops of lignite along the bluffs and foothills of the region point to a wide distribution in Union County of the clay beds exposed in the section given above.

A specimen of the clay bed No. 6 of the Wilmington Landing section was analyzed.

Analysis of buff clay from Wilmington Landing.

[Specimen dried at 135° C. W. A. Noyes, analyst.]

Silica (SiO_2)	64.97
Titanic oxide (TiO_2)	.40
Alumina (Al_2O_3)	18.87
Iron oxide (Fe_2O_3)	5.26
Lime (CaO)	.63
Magnesia (MgO)	1.00
Potash (K_2O)	1.43
Soda (Na_2O)	.30
Water (H_2O)	7.43
	100.29

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The large percentage of iron in this sample is probably due to infiltrations, the specimen having come from near the surface. Clay under cover will probably be found freer from this impurity and available for pottery ware and for other purposes for which basic clays may be used.

CLAY INDUSTRY.

But one plant in Union County is engaged in the manufacture of clay products—the Felsenthal Brick Company, at Felsenthal. The plant was established in 1904 for the manufacture of stiff-mud building bricks. They are made from the common surface red clay. The clay is tempered and molded in a Sword machine run by steam. The bricks are dried in a shed and burned in an up-draft kiln. Four kilns are in use, each having a capacity of 200,000 bricks. It requires six to ten days for the bricks to dry sufficiently to set in the kiln, and from six to eight days for burning. Wood is used as fuel. The plant has an output of 30,000 bricks a day.

The potter's clays of Union County are not utilized. There was at one time a pottery on what was formerly known as the "poor-house farm," sec. 34, T. 17 S., R. 15 W., a little more than a mile southeast of Eldorado. It was operated by Mr. Leonard as late as 1860, and was probably closed by the civil war. The pottery made is said to have been of ordinary grade. The clays used are reported to have come from the "slashes" and not from a bed in place in the hills.

There was another pottery in Union County before the civil war, about 4 miles below Wilmington Landing. The ware burned light gray and was of good texture. The clay came from the stratified beds in a bank. This pottery is no longer in existence.

There is no lack of clays in Union County for the manufacture of good pottery and of fire-clay goods. It is possible that valuable clays may cover as much as half of the total area of the county. Though analyses have not been made of all the varieties of clay found in Union County it may safely be assumed that the clays are similar to those of Ouachita County, many of which have been analyzed. Until recently there was a lack of prompt transportation, for there was no railroad in the county, but the railroad from Camden to Eldorado and other railroads lately completed now afford cheap transportation for any clay goods that may be manufactured from the fine clays along Ouachita River.

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WHITE COUNTY.

GENERAL GEOLOGY.

PRINCIPAL FEATURES.

The part of White County lying west of the St. Louis, Iron Mountain and Southern Railway is made up chiefly of sandstones, grits, and shales belonging to the lower Carboniferous or Mississippian series. In the extreme northwest corner of the county, about Rosebud and Romance, these beds are very nearly horizontal, and the streams have cut through the steep-sided and rather narrow valleys. Here the harder beds of sandstone form broad, flat areas with rather abrupt edges. In the southwestern part of the county and in the region between Searcy and Griffin Springs the same series of beds has been greatly folded, so that the beds dip toward the south on one side of the folds and toward the north on the other. In the folded area the alteration of hard beds of sandstone with soft beds of shale has given rise to alternate valleys and ridges, for the resisting sandstones withstand weathering and form the ridges, while the beds of shale break down into soft, easily washed clays, which are carried away, forming the valleys. The relations of these interfolded shales and sandstones are of great importance to anyone studying the distribution of the clays and clay shales, for it often makes it possible to trace the same bed for many miles across the county.

In the region just north of the town of El Paso the parallelism of the sandstone ridges and shale valleys is a striking feature of the topography. These ridges and valleys begin a few miles west of Buble and some of them swing northward around Antioch Mountain and then pass nearly due west to the vicinity of Caldron Creek, just north of Conway, in Faulkner County. Similar ridges beginning just north of the town of Austin can be traced nearly to Palarm Bayou, south of Preston, in Faulkner County. The valleys parallel with these sandstone ridges are all cut in shales, and it is to these shales that attention is directed. Some of these shales are too sandy to be utilized, but others are well adapted to the manufacture of paving brick and sewer pipe, and some of them are good fire clays.

The geology of Round Mountain, in the extreme southwest corner of White County, has been examined for the purpose of determining the character of these shales. The geology of that particular hill is therefore given here in detail.

ROUND MOUNTAIN.

A great syncline or troughlike valley known as Cypress Valley extends from the vicinity of Beebe to Arkansas River west of Conway. In the middle of this synclinal, in White County, in secs. 5, 6, 7, and 8, T. 5 N., R. 10 W., stands an isolated table-topped hill known as

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Round Mountain. This hill rises about 200 feet above the surrounding valley, and has in general outline, as seen on a map, the form of a dumb-bell.

The sections given in fig. 19, taken at the opposite ends of the mountain, and the north-south profile section in fig. 20 show that while Round Mountain contains some coal and is capped by sandstone it is made up for the most part of argillaceous shales.

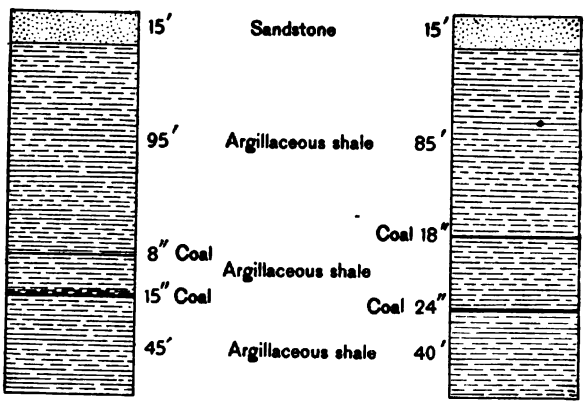

FIG. 19.—Sections of beds at Round Mountain.

The coal bed in section 2, fig. 19, was reported to have a thickness of 42 inches until 1892, when Mr. Charles Kantorowicz, of Little Rock, the owner of the Round Mountain property, engaged Capt. R. N. Scruggs to open the drift and definitely determine its thickness. The thickness here reported is that given by Captain Scruggs.

Where the shales near the base of the mountain have been covered by the débris from its sides they are already deeply disintegrated. The great body of the hill, however, is of compact shale, weathering

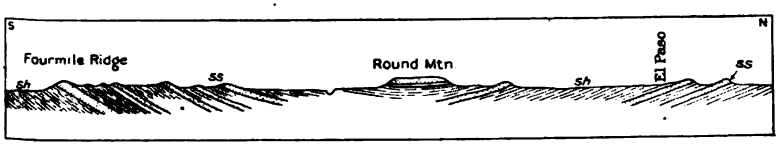

FIG. 20.—Theoretic north-south section through Round Mountain. *sh*, Shale; *ss* sandstone.

in the usual way on exposure and breaking up in small prisms and cuboidal fragments. Much of this shale, possibly all of it, is available for the manufacture of fire bricks, sewer pipes, furnace linings, etc., and for road-paving bricks. The following are analyses of two samples of shales from Round Mountain and of two other similar shales from Missouri and Ohio, the analyses of the latter being introduced here for comparison:

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Analyses of shales from Round Mountain, Ark., Cheltenham, Mo., and Akron, Ohio.

	Round Mountain.		Missouri.	Ohio.
	1.	2.	3.	4.
Silica (SiO_2)	64.04	57.12	56.86	60.05
Alumina (Al_2O_3)	21.55	24.32	28.07	20.00
Ferric oxide (Fe_2O_3)	5.01	8.21	5.03	6.82
Lime (CaO)	.59	.72	.27	.52
Magnesia (MgO)	.96	1.74	.32	.45
Potash (K_2O)	1.56	2.07	.11	1.79
Soda (Na_2O)	.80	.53	.96	1.60
Loss on ignition	5.94	7.58	10.88	6.96
Sulphur (S)	.14	.22	.....	1.95
	100.59	102.51	102.50	100.14
Water loss at 110°-115° C	1.36	1.75	3.84	1.25

1. From the bed of shale lying between the two coal beds exposed at west end of mountain. J. P. Smith, analyst.
2. From above uppermost bed of shale in the section. J. P. Smith, analyst.
3. From shale banks at Cheltenham, Mo. This is the material of which the Laclede Company manufactures its fire-clay goods. Brackett & Smith, analysts.
4. From Akron, Ohio; material used in the manufacture of sewer pipes, etc. Brackett & Smith, analysts.

A comparison of these analyses shows that the clay shales of Round Mountain are well adapted to the manufacture of fire bricks, sewer pipes, and such goods as are made of the similar clay shales at Cheltenham, Mo., and Akron, Ohio, as well as of paving bricks for roadways.

The coal in Round Mountain may perhaps be utilized in connection with the shales. At the west end of the mountain Mr. W. S. Brewer has opened a drift on a bed of coal which he reports to be 14 inches in thickness.

Immediately above the coal lies 20 to 24 inches of coal dirt or crushed bony coal. During and since the civil war Mr. Charles Kantorowicz's coal mine at the east end of the mountain was operated, but the drift has been abandoned since the spring of 1877, and the opening has been closed by the caving in of its sides. It was therefore impossible to examine the thickness of the coal bed at this place at the time it was visited. In 1892 Mr. Kantorowicz employed Capt. R. N. Scruggs to open the drift, and it was found that the coal was 24 inches thick 41 feet from the outcrop. Unfortunately it has not been possible to obtain a sample from the Kantorowicz mine, but analysis was made of a sample from Mr. Brewer's pit, which probably fairly represents the quality of coal of this lower and more important bed. The specimen was taken from the 8-inch bed high on the side of the mountain, and the coal is of good quality, as may be seen from the following analysis:

Analysis of Round Mountain coal.

[R. N. Brackett, analyst.]

Water	1.224
Volatile matter	10.298
Fixed carbon	78.119
Sulphur	3.149
Ash	7.210

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Round Mountain is easy of access either from Beebe or Conway, Cypress Valley being well disposed for the location of a railway line.

Cypress Valley, especially the country about Round Mountain, abounds in good brick clays, while the region is well timbered.

There are other shale hills in the Cypress Valley syncline, the largest of which is about 7 miles east of Conway, Faulkner County, in secs. 11 and 14, T. 5 N., R. 12 W., in a hill which is also known as Round Mountain. The body of the hill is of dark argillaceous shale capped by sandstone. The rocks are identical in age and character with those of the White County section, except that thus far no coal beds have been found in the Faulkner County hill. This hill rises between 250 and 300 feet above the valley and is nearly a mile long.

In secs. 11 and 14 of the same township and range there is another shale hill that is identical in structure and character with the one just mentioned, though somewhat smaller and only about half a mile long.

CLAY DEPOSITS.

CLAY SHALES.

In addition to the localities specified above as containing large and accessible clay shale deposits, it should be remembered that the parallel valleys of White, Faulkner, and Conway counties are, for the most part, underlain by clay shales, many of which are available as refractory materials for various uses.

In the highlands the brick clays are most abundant in the shale valleys. The valley lying just northwest of Searcy and swinging north and northeast in the vicinity of Center Hill and opening into the Red River Valley east of Mount Pisgah may be taken as typical of those shale valleys of the county in which considerable deposits of brick clays have accumulated. In places these clays are spread out in thin beds for miles over the valley, in others the beds are from 10 to 20 feet thick, while in still other small areas they are entirely absent.

Along some of the larger streams, such as Red River, Big Indian Creek, and Bayou des Arcs, the bottom lands are largely buckshot clay with alluvial soil adjacent to the streams. In the immediate valley of Cypress Bayou good brick clays are abundant, especially about the headwaters of that stream and in the vicinity of Round Mountain, in T. 5 N., R. 10 W.

In the region of the lower hills the brick clays are at many places of great thickness. The following is a section of a well bored near Pangburn post-office, in the northwest corner of the county, in the NE. ¼ NE. ¼ sec. 10, T. 9 N., R. 8 W. This record was kindly furnished by Dr. F. L. Shaw, of Pangburn.

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Section of well near Pangburn post-office.

	Feet.
Brick clay	16
Hard sandstone	4
Black shale	70
Hard blue sandstone	4

The western part of White County is mountainous, and on the highest elevations the brick clays, although not altogether wanting, are not so thick or abundant as in the lower lands.

TERTIARY AND QUATERNARY CLAYS.

From Cypress Bayou to Bradford the St. Louis, Iron Mountain and Southern Railway runs through White County just east of the line of junction between the Carboniferous hills on the west and the Tertiary and Quaternary deposits of the lower flat country to the east. This line divides the county into two sections which differ widely from each other in geologic age and in character. The clays of the two areas also differ more or less. Those of the hilly region are derived directly from shales by decomposition. The clays in the lowlands and valleys are the products of the erosion of the higher points, while the clays of the lowlands farther east are often horizontally stratified. Good brick clays are abundant in various parts of White County, especially along the line of the St. Louis, Iron Mountain and Southern Railway.

The Tertiary and Quaternary clays along the Iron Mountain Railway are, according to Mr. Kennedy, made up of two divisions. The upper division is a brownish-yellow sandy clay of very nearly the same texture throughout. In places it has a greater proportion of clay; in others it is nearly a sandy loam, while in still others it is a clean sand. It varies also in color from a brownish yellow to dark orange, or even red.

The second or underlying division is usually a dark-bluish clay, somewhat brownish when damp and weathering almost white when dry and exposed for some time. In some places this clay is of a reddish color, owing to the presence of a greater quantity of iron. Although this lower bed is somewhat lighter in places, it does not materially vary in texture or composition, and wherever found in the region as red, white, or blue clay it is essentially the same material, has the same qualities, and is available for the same uses. In comparing the well records in the district these variations in color have to be taken into consideration, for observers may report the same beds as having different colors.

These two deposits vary considerably in thickness in different parts of the county. The underlying bluish-white clay is persistent over the whole area, but the brownish-yellow clay, overlying the

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blue, is by no means so extensive and is at some places altogether absent. In the Beebe district the brownish-yellow surface material varies from 3 to 6 feet in thickness. At Searcy it is 3 feet thick, while a mile west of Searcy, in a well, it is only 2 feet 6 inches thick, and it has the same thickness (2 feet 6 inches) at Judsonia.

Wells in the neighborhood of Kensett show that the upper clay there is very irregular in thickness, while in some of them it is wanting altogether. In the Briggs well, in the S. ½ NW. ¼ NE. ¼ sec. 16, T. 7 N., R. 6 W., it is 2 feet thick. On the road near Captain Moseby's house, about a quarter of a mile south-southeast of Moseby's gin house, in the NW. ¼ NW. ¼ sec. 15, T. 7 N., R. 6 W., it is 3 feet thick. At West Point an extensive area is altogether devoid of any such covering, while the railway from that place to Kensett shows it in various places to have a thickness of 2 to 4 feet.

Brownish-yellow clay or earth suitable for the manufacture of brick is found in spots throughout the area under consideration, but most of these areas are too small to be shown on a small map. These spots occur in rolls or on the tops of ridges, and may, as at Judsonia, occupy parts of secs. 8, 9, and 17. At Searcy the brownish-yellow earth extends over an area that is possibly a quarter of a mile wide and three-quarters of a mile long, occupying the small valley running west from the town of Searcy through the centers of secs. 10 and 9 and the middle of sec. 8, T. 7 N., R. 7 W. This area includes the best brick clays in this neighborhood.

The sections exhibited in the well borings from Cabot, Beebe, Kensett, and Judsonia, in a continuous line, as well as those along the lines from Searcy to West Point, show the persistence of the underlying bluish-white or bluish-brown clay. This clay is dark bluish brown when moist and gray when dry. The light-gray appearance is due to patches of pale-blue clay embedded in the mass. When exposed at the surface and allowed free contact with the rain these whitish or pale-blue spots become fluid and spread over the face of the cutting, giving the whole a light appearance. This clay contains also numerous patches stained with iron and some almost black. The following sections show the relations between the upper yellow loam deposits and the lower blue clays and sands:

Section in C. Essig's well, near Beebe.

	Feet.
1. Surface clay	4
2. Bluish clay with dark-colored and iron-stained patches	10
3. Joint clay	20
4. Yellow sandy clay	14
5. Quicksand	7
	55

No. 1 of this section is used for bricks and No. 2 for drain tile.

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In the W. ½ N. ½ NE. ¼ NW. ¼ sec. 8, T. 5 N., R. 8 W., a well dug by Mr. Parker gives the following:

Section in Parker's well.

	Feet.
Yellow loam	6
White joint clay	12
Red sandy joint clay with pebbles	35
	53

W. A. Ballou has a well at Beebe 20 feet deep, which shows—

Section in Ballou's well.

	Feet.
Yellow clay	3
Bluish clay	17
	20

Part of the upper division of the lower bed is dug and mixed with 3 feet of yellow clay for brick clay, and the articles so made burn better and are much harder than those made from the yellow brick earth alone.

That part of White County lying east of the St. Louis, Iron Mountain and Southern Railway has not been examined except at West Point. The general geology of the region, however, is inferred to be very nearly identical with that of Lonoke and Prairie counties. Good brick clays are likely to be found throughout most of the eastern part of White County. In the wet lands or slashes the limonite buckshot is found in the clays a short distance below the surface, and, as is well known, these nodules injure clays more or less for brickmaking purposes. The best brick clays of White County are found on the higher lands.

CLAY INDUSTRY.

The upper yellow clays are made into bricks at Beebe, Searcy, and Judsonia, and a mixture of the yellow and upper portion of the bluish clay is also used. The blue clay beneath was formerly also used by Mr. C. Essig at Beebe for the manufacture of drain tiles. The Beebe clay makes hard, solid bricks, but their color is not satisfactory and they can not therefore be used for facing and other purposes where ornamental or fine bricks are required. Their color when properly burned is a light gray, sometimes running into a dark cream, but they are not of a uniform shade. These bricks are well adapted for use in foundations where a sound, hard brick is required without regard to its roughness of appearance or poor color.

When the brownish-yellow upper bed is used alone the clay is worked in a very soft condition and in drying shrinks considerably and shows a tendency to warp. A mixture of the two clays forms a brick which, although coarse, is of good quality, and is less liable to

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shrink or warp. The mixing of the clays, however, requires a great amount of care and time. The material of the lower bed must be dug up and allowed to lie for some time before it is incorporated with the upper clay.

If the clay were dug from the lower bed during the fall of the year and left exposed to the disintegrating influences of the rains and frosts of the winter and spring its texture for brick or tile making purposes would be materially altered and improved. By such treatment it would be pulverized, mellowed, and almost completely tempered, and with slight additional treatment could be manufactured into bricks of a bright-red color, more uniform than those made from the upper bed alone, and of better texture than those made either from the upper clay or from a mixture of the two.

As a material for the manufacture of drain tiles this winter-mellowed clay would serve a very good purpose. It would turn out a stronger tile than any at present used.

In May, 1905, Mr. J. Y. Woodson was operating a brick plant at Searcy, one-half mile west of the court-house. The yellow surface clay is used to a depth of 3 feet. The mud is pugged in a ring pit with a Raymond wheel run by horse power, and must be ground for one and one-half to three hours before it can be molded. In the summer, when the clay is dry, it requires 200 to 250 gallons of water to temper sufficient mud to make 1,000 bricks. In the winter it requires less than half that amount of water.

The bricks are common wet-mud bricks molded by hand and dried in racks in the open air. They are burned in up-draft kilns of 200,000 capacity. Wood is used for burning, and about three-fifths of a cord is used for each 1,000 bricks. The bricks require twelve to fourteen days for drying and six to eight days for burning. The plant is operated by six men and three boys, and the output is about 5,000 bricks a day.

WOODRUFF COUNTY.

GENERAL GEOLOGY.

The surface of the western half of Woodruff County is composed of the alluvial bottom lands of White and Cache rivers. The surface of the eastern half varies from a reddish clay to sandy prairie land, 25 to 30 feet higher than the bottoms of Cache and White rivers. The prairie area is cut into north-south ridges by Bayou de Vue, Buffalo Creek, Caney Creek, and other small streams. The most prominent of these ridges is Nubbin Ridge, which has a north-south trend through R. 2 W. The top of this ridge is 25 to 30 feet above the Cache River bottom to the west. The soil on Nubbin Ridge is much poorer than the rich alluvial soils of the bottoms to the east and west.

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The geologic strata of the county belong to two distinct periods. The bottom lands are all alluvial sands, which are now being formed by the present streams. The prairie lands and ridges belong to a much earlier period in Quaternary time.

Where the railroad passes up to Nubbin Ridge from the bottom land just south of Colona the cut shows the following section:

Section of Nubbin Ridge near Colona.

	Ft.	in.
Soil		10
Reddish to yellowish-tinted loamy clay, containing buckshot concretions; practically impervious to water	2	2½
White sandy clay, sharply separated from the above by its lack of moisture, and grading down into a reddish resistant sand, and this to a purple loose sand	10	

The same order of strata that is given above is seen in the road a short distance west of Powell.

The typical prairie lands in the western part of St. Francis County extend westward into Woodruff County. The following section was obtained in wells at Hunter:

Section of wells at Hunter.

	Ft.	in.
Soil (a few inches) at top.		
Red clay, sticky and soft when wet	2	6
White clay		3–6
Hardpan (clay)	9–15	
Clay and yellow sand, very hard when dry	5	
Fine gray sand	5	
White sand	4	
Quicksand with some gravel, water bearing	3	
Hardpan	3	
Sand becoming coarser at bottom, water bearing	35–45	

CLAY INDUSTRY.

At present there is but one plant in Woodruff County where clay is utilized. This is a common wet-mud brick plant located at Cotton Plant. The bricks are made from the yellow loam which occurs in the prairie section of the county. There are no large towns in the county except Augusta, which is located in the alluvial sands of White River, so that the local demand for building brick is not great.

YELL COUNTY.

GENERAL GEOLOGY.

The general geology of Yell County is similar to that of Pope and Logan on the north and to that of Scott and Logan on the west. The clays therefore fall naturally into the same classes, namely, (1) Carboniferous shales and clays interbedded with the hard rocks in place; (2) brick loam and buckshot clays; (3) terrace clays along Arkansas River; (4) clays of the Arkansas River flood plains.

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CLAY DEPOSITS.

CARBONIFEROUS CLAY SHALES.

In Yell County the great shale member at the top of the Atoka formation is again one of the most prominent and important of the Carboniferous rocks. This shale enters Yell County on the west, on the south side of Magazine Mountain 2½ miles west of Waveland, and extends along the south side of both Magazine and Chickahah mountains. At the east end of Chickahah Mountain it runs round the end and then, turning westward, extends along the base of the ridge until it joins the same outcrop around the base of Huckleberry Mountain. The same beds run entirely around Three Knobs Mountain, around Spring Mountain, and around Mount Nebo. The shale bed underlying the sandstone on the south side of Dardanelle Ridge is this same shale.

Shales lower in the geologic scale are exposed over a large part of Yell County. At Chickahah village and in the valley thereabout there are many exposures of such shales. At Danville shales are well exposed along Petit Jean Creek with a dip N. 60° W., varying from 20° to 24°. These shales extend over the flat valley for miles east of Danville. On the Rover road south of Danville and on the north side of Danville Mountain there are many exposures of clay shales interbedded with sandstones, and these alternations of shale and sandstone continue to the top of Danville Mountain. Along the road running from Danville to Ola, along the base of the mountain, the rocks are nearly all shales and all dip toward the north. At Ola, on the Choctaw Railway and just south of the railroad station, is a cut, 12 feet deep, in shales. A few hundred feet west of the station there is a large exposure of promising looking shales in the railroad cut. Along the road leading from Ola toward Dardanelle shales are exposed at many places for a mile or more, all of them dipping northward. Where the Ola-Dardanelle road crosses Petit Jean Creek the flaggy shales dip N. 80° E. at an angle of 14°. On the ridge a mile north of Dardanelle the red clay is underlain by fissile shale dipping north and passing beneath Dardanelle Rock.

BRICK LOAM AND BUCKSHOT CLAYS.

The brick loam or yellow and ashen buckshot clays cover a large area in the lowlands of Yell County; indeed, there is probably more clay of this kind in Yell than in any other county in the State. The clays are especially abundant and thick along Petit Jean Creek from the point where that stream enters the county, 3 or 4 miles southwest of Waveland, to the place where it empties into Arkansas River—a distance of about 50 miles. In places south of Dardanelle the yellow loam is exposed to a depth of fully 12 feet, yet the total thickness of the deposit is not visible.

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The following are a few localities at which the brick loam has been noted: On the upper Dardanelle-Danville road 3 miles from Dardanelle, at a place where the road crosses the stream, the loam is 6 feet thick, with sandstone fragments at the base. It is a widespread deposit in the lower parts of the valley between Chickahah and Belleville and between Belleville and Danville. The valley soil about Danville is mostly the "buckshot" loam. In many of the low red-clay hills along Harris Creek several feet of yellow clay lies beneath the red clay, and waterworn pebbles beneath the yellow. At Johnsons Bridge, on the lower Dardanelle-Danville road 1 mile southwest of Dardanelle, the yellow loam is at least 12 feet thick. This exposure is especially interesting because it exhibits the relations of the chocolate clays of the river country. The following is the section:

Section at Johnsons Bridge.

	Feet.
Greenish-yellow loam with some waterworn cobbles	4
Chocolate clay with calcareous concretions and nodules	4–8
Yellow sandy clay with calcareous matter in crevices	12

The demarcation between the chocolate clay and the underlying yellow sandy clay is very clear at this locality. The lower bed is deeply scored by big gullies that are in places as much as 12 feet deep. The calcareous matter of the lower bed is derived from that of the chocolate clay by solution and redeposition, as is indicated by the fact that the concretions of the lower bed occur mainly in cracks and are not disseminated through the mass as they are through the chocolate clays.

The following section is an analysis of the lower yellow clay of the Johnsons Bridge section:

Analysis of the lower yellow clay at Johnsons Bridge, 1 mile south of Dardanelle.

[Specimen dried at 110°–115° C. J. P. Smith, analyst.]

Silica (SiO_2)	74.48
Ferric oxide (Fe_2O_3)	7.52
Alumina (Al_2O_3)	11.58
Lime (CaO)	.64
Magnesia (MgO)	.26
Manganese oxide (MnO)	.41
Potash (K_2O)	1.10
Soda (Na_2O)	.54
Loss on ignition	4.11
	100.64
Water at 110°-115°C.	1.83

TERRACE CLAYS ALONG ARKANSAS RIVER.

Certain clays and silts along Arkansas River are quite different from any found in the Paleozoic region away from that stream. Such are the loams used for the manufacture of common bricks at

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Argenta and at Fort Smith. The same clays occur in Yell County in the second bottoms, usually well away from the river. But as the Yell County line follows this river for 28 miles, there is an abundance of this material in the second bottoms, especially between Dardanelle and the mouth of Petit Jean Creek. Over the pink and yellow clays that form most of these terraces lie patches of what the Arkansas Geological Survey has called chocolate clays. These chocolate-colored clays are very fine silts, and are extremely plastic and sticky when wet. When dried they often break up in small angular and conchoidal fragments and are sometimes called "buckshot" clays, not on account of the presence of the iron nodules that characterize the true "buckshot" loams, but because it falls to pieces in these small lumps about the size of a buckshot. These chocolate clays have thus far been found in the State only within the area subject to overflow by Arkansas River, and it has therefore been supposed that they are silt deposits made by that stream. The section at Johnsons Bridge just given shows that the chocolate clay is of later age than the yellow and pink loams of the second bottoms. The chocolate clay usually contains an abundance of lime nodules. The clay itself is also high in lime, as is shown by the following analysis:

Analysis of chocolate clay from Johnsons Bridge, near Dardanelle.

[Specimen dried at 110°–115° C. Brackett & Smith, analysts.]

Silica (SiO_2)	56.91
Iron (Fe_2O_3)	6.68
Alumina (Al_2O_3)	19.80
Lime (CaO)[a]	4.76
Magnesia (MgO)	.96
Potash (K_2O)	2.12
Soda (Na_2O)	1.05
Loss on ignition	9.57
	101.85
Water at 110°–115° C.	7.77

A qualitative examination of the nodules in the chocolate clay showed that they consist chiefly of lime carbonate, but they contain considerable iron and magnesium.

The chocolate clay overlying this yellow sandy clay at Johnsons Bridge and elsewhere in the neighborhood has been tried for brick-making, but without success. Indeed, it may be set down as a rule that the chocolate clay, wherever found in the State, is unsuited to brickmaking.

[a] Some of the lime is in the form of carbonate, but the carbonic acid was not determined.

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ALLUVIAL CLAYS ALONG ARKANSAS RIVER.

The clays of the great flood plain of Arkansas River are confined to the river bottoms proper. They are for the most part extremely variable in character and thickness and hold out but little promise of being useful as clays.

CLAY INDUSTRY.[a]

POTTERY.

In the SE. ¼ SE. ¼ sec. 12, T. 6 N., R. 21 W., a deposit of light-bluish, red-streaked clay overlies the black shales to a depth of 3 to 5 feet. This same clay covers the greater part of the section. Some years ago it was worked as a pottery clay, and was manufactured into a strong, dark-red earthenware. When glazed the material used for the purpose was broken glass and soda, which gave the ware a peculiar greenish color. This clay may be suitable for sewer pipes or any ware requiring a strong plastic clay capable of burning to the verge of vitrification and taking a salt glaze.

In the E. ½ SE. ¼ sec. 11, T. 6 N., R. 21 W., soft blue argillaceous shales appear to underlie 3 feet of broken red shales and sandstones.

COMMON BRICKS.

In the NE. ¼ NE. ¼ sec. 1, T. 6 N., R. 21 W., bricks have been made from a light-yellowish sandy clay. This clay is about 2 feet thick and overlies a red clay. The red clay forms the surface soil in the northern part of the same section and also in part of the NW. ¼ NW. ¼ sec. 6, T. 6 N., R. 20 W. No bricks have been made in this yard since 1886. From the broken pieces of brick lying on the yard they appear to burn to a salmon color when soft, and when burned hard are gray and spotted with iron.

On lot 2 of the NW. ¼ SW. ¼ sec. 6, T. 6 N., R. 20 W., bricks were made some years ago by Messrs. Perry & Kimball and afterward by Mr. R. Smiley. A yellowish clay containing small white calcareous concretions was used for the manufacture of these bricks. This clay is unsuited for hand molding, and the bricks were made on a Hotchkiss machine. Owing to the stiffness of the clay and the tendency of the green bricks to crack when exposed to the sun, there was considerable difficulty in drying them until drying sheds were built. Under cover the bricks dried very slowly, but without much loss through breakage. In burning these bricks the firing was kept up for twelve to fourteen days. The shrinkage or settling in the kiln is said to have been considerable, but no reliable information could be obtained on the subject. The eye bricks showed a slight tendency

[a] The notes on the clay industries of Yell County were made by Mr. William Kennedy.

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to vitrification and were of a dark metallic-blue color. The bricks were hard and apparently durable, some of them put down in a pavement twelve years ago being still sound. In the SW. ¼ SE. ¼ sec. 29, T. 6 N., R. 20 W., J. F. Nolan burned a few bricks in 1888. The earth used by him is of orange color. The bed is 2 feet thick and extends over an area of 30 acres. The bricks burned hard and range in color from a dark cherry-red to a light gray. The hard-burned bricks are spotted with dark iron stains. The loss at this kiln amounted to about one-third.

The only plant in operation in the county at the present time (1906) is run by William Murphy, at Dardanelle, for making common bricks. No further information concerning this establishment was obtained.

ANALYSES OF CLAYS.

In the table of analyses of pottery, fire, and other clays of Arkansas given on pages 236–237, certain typical clays of Ohio and Missouri are also included for purposes of comparison.

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Analyses of pottery, fire, and other clays.

Laboratory No.	Location.	Silica (SiO_2).	Alumina (Al_2O_3).	Ferric oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Potash (K_2O).	Soda (Na_2O).	Loss on ignition.	Total.	Water at 110°–115° C.
	POTTERY CLAYS OF ARKANSAS.										
276	NW. ¼ NE. ¼ sec. 12, T. 2 S., R. 15 W	65.79	23.92	1.94	0.23	Trace.	1.15	1.08	7.07	101.08	1.80
277	NW. ¼ NE. ¼ sec. 12, T. 2 S., R. 15 W	72.44	18.97	1.59	.18	Trace.	1.35	.91	5.39	100.83	1.55
278	NW. ¼ SW. ¼ sec. 12, T. 2 S., R. 15 W	69.95	22.34	1.44	Trace.	.08	1.28	1.18	5.98	102.25	2.34
279	SE. ¼ sec. 2, T. 2 S., R. 15 W	71.09	19.86	1.81	.11	Trace.	1.45	.81	5.67	100.80	1.96
305	NW. ¼ NW. ¼ sec. 1, T. 2 S., R. 15 W	64.49	23.86	2.11	.31	Trace.	.11	1.82	8.11	100.81	2.37
[a] 338	NE. ¼ NE. ¼ sec. 24, T. 4 S., R. 17 W	73.24	14.61	1.04		0.78			5.33	100.00	2.01
336	NE. ¼ SE. ¼ sec. 18, T. 13 S., R. 24 W	76.33	16.04	1.24		.99			5.40	100.00	2.23
339	NE. ¼ SE. ¼ sec. 18, T. 13 S., R. 24 W	73.87	17.38	1.64		1.46			5.65	100.00	1.92
337	W. ½ SE. ¼ sec. 5, T. 15 S., R. 25 W	75.99	16.12	1.35		1.45			5.09	100.00	1.08
[b] 340	NE. ¼ NW. ¼ sec. 9, T. 15 S., R. 28 W	74.85	17.20	1.12		1.13			5.70	100.00	1.53
[c] 328	S. ½ SE. ¼ sec. 27, T. 7 N., R. 30 W	81.61	10.52	2.70	0.32	0.40	0.66	0.57	3.95	100.73	3.86
329	SE. ¼ NW. ¼ sec. 36, T. 10 N., R. 32 W	67.64	21.57	2.48	.27	.62	1.63	.57	5.53	100.31	2.85
	FIRE CLAYS OF ARKANSAS.										
333	NW. ¼ NE. ¼ sec. 34, T. 8 N., R. 26 W	88.66	5.73	2.55	.....	.81	.....	.....	2.25	100.00	1.33
334	Clarksville (in stream opposite college)	53.36	29.96	5.12	.30	1.16	2.69	1.03	7.90	100.52	3.90
[b] 341	NE. ¼ SW. ¼ sec. 2, T. 12 S., R. 18 W	76.21	16.00	.75	.....	1.06	.....	.....	5.98	100.00	.....
[b] 342	W. ½ SE. ¼ sec. 5, T. 15 S., R. 25 W	75.32	16.75	.92	.....	1.87	.....	.....	5.14	100.00	1.54
343	.....do	74.76	15.96	3.44	.51	1.10	2.28		3.95	100.00	3.33
344	NW. ¼ SE. ¼ sec. 18, T. 13 S., R. 24 W	72.48	18.24	1.52	Trace.	.....	1.98	.....	5.78	100.00	1.69
345	NE. ¼ NE. ¼ sec. 24, T. 4 S., R. — W	72.59	16.08	1.18	Trace.	.26	3.55		6.34	100.00	2.18
347	SW. ¼ NW. ¼ sec. 4, T. 7 N., R. 18 W	90.49	5.22	1.38	.....	.....	.....	.....	3.12	100.00	1.60
352	SE. ¼ SW. ¼ sec. 12, T. 10 N., R. 26 W	62.92	23.60	3.17	.23	.57	2.77		6.74	100.00	2.65
99	SW. ¼ NW. ¼ sec. 16, T. 9 N., R. 31 W	64.63	23.71	3.71	.31	.41	2.03	0.94	6.52	102.26	3.02
351	NE. ¼ NW. ¼ sec. 14, T. 12 S., R. 18 W	79.42	13.35	2.17	Trace.	.....	.....	.....	5.38	100.32	3.72
286	Mabelvale station	65.27	18.75	7.34	.81	1.26	1.10	1.81	6.88	102.22	9.46
[d] 110	Towson road, Fort Smith	58.43	22.50	8.36	.32	1.14	2.18	1.03	6.87	100.83	3.37
267	Iron Mountain Rwy., near Mount Ida wagon road	62.36	25.52	2.16	.51	.29	1.90	.66	5.32	98.72	1.99
[e] 270	Faulkner County	64.04	21.55	5.01	.59	.96	1.51	.80	5.94	100.40	1.36
71	Harding & Boucher's quarry, Fort Smith	57.10	23.74	8.18	.53	1.04	1.53	.87	7.21	100.20	4.20
	NW. ¼ SW. ¼ sec. 28, T. 8 N., R. 28 W	65.12	19.05	7.66	.34	.31	1.23	.85	6.12	100.68	4.79
	SUNDRY CLAYS OF ARKANSAS.										
[f] 51	Johnsons bridge	56.91	19.80	6.68	4.76	.96	2.12	1.05	9.57	101.85	7.77
174	Fort Smith	76.26	11.74	4.54	.39	.79	1.28	.98	3.82	99.80	3.71
[g] 330	River deposit	70.95	12.24	4.73	1.90	.97	1.14	.66	7.01	99.60	4.19

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343	W. ½ SE. ¼ sec. 5, T. 15 S., R. 28 W	74.70	13.96	3.44	.51	1.10	2.28	3.95	100.00	3.33
f 274	Union depot, Little Rock	70.05	14.50	6.20	.74	1.12	Not determined.	4.45	97.12	4.48
280	NW. ¼ sec. 30, T. 1 N., R. 11 W. (on railroad)	90.38	4.48	2.10	.16	Trace.	0.41 0.66	1.91	100.10	1.91
173	Railway at Ketchum Iron Co.'s works	83.83	9.32	2.04	.34	.45	1.27 .85	2.40	101.10	2.21
117	South end of railway to Dardanelle	76.20	12.41	4.36	.49	.54	1.21 .84	3.75	99.80	4.06
335	NE. ¼ SW. ¼ sec. 15, T. 1 S., R. 14 W	82.45	11.80	.80	.31	.25	1.60	2.79	100.00	.21
h 332	Albany (slip clay)	58.05	14.86	6.76	6.61	3.08	1.18 0.80	7.41	98.75	1.66
	CLAYS FROM OHIO AND MISSOURI.									
i 109	Carboniferous shales from Akron, Ohio	60.05	20.00	6.82	.52	.45	1.79 1.60	6.96	98.19	1.25
j 264	Carboniferous shales from Akron, Ohio	73.77	17.40	1.88	.49	.31	.61 1.55	5.41	101.42	1.10
311	Cheltenham, Mo.*k*	56.86	28.07	5.03	.27	.32	.11 .96	10.88	102.50	3.84
312	Cheltenham, Mo.*k*	54.92	22.71	9.81	.52	2.59	3.16 .62	5.88	100.21	2.69

a Pink clay.
b Slight trace of lime.
c Slight trace of manganese.
d Sulphur, 0.16.
e Sulphur, 0.14.
f Chocolate clay; brick clay.
g May be used as slip clay.
h Used as a slip for black glazing by all potters in the State.
i Sulphur, 1.95; used at Akron, Ohio, for the manufacture of sewer pipes.
j Sulphur, 0.08; pottery clay.
k Used by the Laclede Fire-Brick Manufacturing Company, St. Louis, Mo.: No. 311, for making fire bricks; No. 312, for making sewer pipes.

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PRODUCTION.

There has been a steady increase in value of the clay products in Arkansas since 1899, as the following figures will show:[a]

Value of clay products of Arkansas 1899–1907.

Year.	Amount.	Year.	Amount.
1899	$339,142	1904	$696,582
1900	381,012	1905	643,956
1901	407,263	1906	532,194
1902	520,178	1907	536,286
1903	589,946		

The output and value of the various clay products of Arkansas for the year 1907 are summarized below. The number of operating firms reporting is 52.

Quantities and values of various clay products of Arkansas in 1907.

	Quantity.	Value.	Average price per thousand.
Common brick	68,463,000	$468,706	$6.85
Vitrified brick	.....	(b)	10.00
Front brick	1,010,000	11,940	11.82
Fire brick	.....	(b)	12.36
Drain tile	.....	5,160	.....
Earthenware and stoneware	.....	16,950	.....
Miscellaneous c	.....	33,530	.....
	.....	536,286	.....

[a] Statistics of the clay-working industries in the United States in 1904, by Jefferson Middleton.
[b] Included in "Miscellaneous" to avoid disclosing the operations of individual establishments.
[c] Includes vitrified and fire brick, hollow building tile or blocks, etc.

LIST OF CLAY WORKERS.

The following table gives a directory of the clay workers in Arkansas in 1906, together with the location of their plants and data concerning materials, processes, etc.

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List of clay workers in Arkansas, 1906.

Location of plant.		Name of firm.	Material used.	Process.	Drier.	Kilns.		Product.
County.	Place.					Number.	Kind of draft.	
Arkansas	Stuttgart	H. C. Bruner	Surface loam					Common bricks.
Ashley	Hamburg	Nolley Bros						
Benton	Bentonville	Bentonville Brick and Tile Co.						Do.
	do	Thomas Haney	Surface clay	Wet mud	Open air		Up	Do.
	Rogers	J. E. Gelabert & Son	do	Hand	do	2	do	Common builders.
	Sloam Springs	W. S. Williams	Common clay	do	Sun		do	Do.
	Sulphur Springs [a]	David J. Young	Shale	Dry press.	Air		Up and down	Face bricks.
Boone	Harrison	J. Samuel Tyson						
Bradley	Warren	Moore & Gannway						
Clark	Arkadelphia	W. A. Obaugh	Surface clay	Wet mud	Sun	2	Up	Common bricks.
	Bradshaw	J. A. Ross						
	Gurdon	N. R. O'Neal	Surface clay	Wet mud	Standard	3	Up	Common builders.
Clay	Pratt [b]	Pratt Brick Co						
Cleveland	Kingsland [c]	Leali Presser and Fire Brick Co.	Shale and surface clay.	Stiff mud and dry press.	Standard	7	Up and down	Fire and common bricks.
Columbian	Magnolia	McIntyre & Co	Red surface clay	Wet mud, handmade.	Sun	1	Up	Common bricks.
Craighead	Jonesboro	Barton Lumber and Brick Co.	Yellow clay	Soft mud and dry press.	Pallet and rack		do	Do.
	do	Jonesboro Brick Co	do	do	do		do	Do.
	do	Logan & Collins						
	do	Patrick Bros. Brick Co	Reworked loess	Wet mud	Pallet and rack		Up	Do.
	do	Sachs Brick and Tile Co	do	Wet mud and dry press.	Closed sheds with steam.		Down	Tile and common building brick.
Cross	Wynne	Wynne Brick Co	Yellow clay	Soft mud	Pallet and rack		Up	Common bricks.
Drew	Monticello	J. H. Blythe, Drew Brick Co.						
Faulkner	Conway	J. W. Firestone	Surface clay	Stiff mud	Shed	2	Up	Common builders.
Green	Paragould	Paragould Brick Co	Reworked loess	Soft mud and dry press.	Pallet and rack		do	Do.
Hempstead	Doyle	L. F. Huddleston						
	Hope	Hope Brick Works	Surface	Wet mud	Pallet and rack	3	Up	
	Spring Hill	Spring Hill Pottery Co	White Tertiary clay		Closed shed		Down	Stoneware.
Hot Spring	Malvern	Clark Pressed Brick Co	Surface clay	Stiff mud and dry press.	Steam		Up	Common builders.
	Perla	Malvern Brick and Tile Works.	Plastic fire clay	Stiff mud	Direct-heat tunnel	4	Down (round)	Fire, paving, and white front bricks.
Howard	Center Point	M. C. Pope	Red surface clay	Wet mud	Open air		Up	Common bricks.
	Nashville	F. M. Buston						
	do	B. F. Hill						
Jefferson	Pine Bluff	O'Neal & Rogers						
	do	Pine Bluff Brick Co	Surface clay	Soft mud	Standard	5	Up	Common builders; also sand-lime bricks.
	Redfield	James H. Conley	Yellow surface clay	Wet mud	do	1	do	Do.

[a] Office at Fort Smith. [b] Office at Rector. [c] Plant to be removed to Little Rock.

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List of clay workers in Arkansas, 1906—Continued.

Location of plant.		Name of firm.	Material used.	Process.	Drier.	Kilns.		Product.
County.	Place.					Number.	Kind of draft.	
Lawrence	Black Rock and Imboden.	Crouch & Courtney	Yellow surface clay	Wet mud	Open air		Up	Common bricks.
	Walnut Ridge	Moore & Co	do	Soft mud	Pallet and rack		do	Common builders.
Lee	Marianna	O. C. Sutton	Reworked loess	do	do	3	do	Do.
Lonoke	Lonoke	W. H. Harrison	Surface clay	do	Open air	2	do	Do.
	Cabat	I. C. Wylie						
Miller	Texarkana	Interstate Pottery	White Tertiary clay		Closed shed		Down	Stoneware.
	do	Anthony W. Stevens						
	do	Texarkana Brick Co	Semishale	Dry press		5	Up	Common builders.
Mississippi	Blytheville	Blytheville Brick and Tile Co.						
Monroe	Brinkley	John C. Moshier	Yellow clay	Hand	Open air	2	Up	Common bricks.
Montgomery	Oden[a]	James & Robinson	Residual clay		Closed shed		Down	Stoneware.
Nevada	Emmet[b]	Longston Bros	Surface clay	Wet mud	Open air		Up	Common bricks.
Phillips	Helena	Straub Pressed Brick Co	Loess	Wet mud and dry press.	do		Up and down	Do.
Pike	Nathan	C. J. Polk	Residual clay	Wet mud	do		Up	Do.
Poinsett	Harrisburg	Harrisburg Brick Co	Reworked loess	Soft mud	Pallet and rack		do	Do.
Polk	Mena	Mena Brick Co	Residual clay	Stiff mud	do		do	Do.
Pope	Atkins	C. B. Wilson	Red surface clay	Hand	Open air	1	do	Do.
	Russellville	Russellville Brick Works						
Prairie	Devall Bluff	Devall Brick Co	do	Wet mud	Pallet and rack	2	Up	Do.
Pulaski	Little Rock	Arkansas Brick and Manufacturing Co.	Surface clay	Stiff mud and dry press.	Standard and open air.	10	Up (Swift's)	Do.
Randolph	Pocahontas	Jansen & Shannon						
	do	Joseph Schmidt	White and gray clay	Wet mud	Open shed	2	Up	Do.
St. Francis	Forrest City	Choctaw Brick and Tile Co	Loess	Stiff mud	Pallet and rack		do	Common building bricks.
Saline	Benton	Benton Brick Manufacturing Co.	Surface clay	Soft mud	do		Up and down	Common bricks.
	do	Eagle Pottery Co	White Tertiary clay		Shed		Down	Stoneware.
Sebastian	Fort Smith	John D. Carbough						
	do	Fort Smith Paving Brick and Fire Clay Co.						
	Mansfield	Choctaw Brick and Gas Co	Shale	Steam mold	Open air	5	Up and down	Common builders.
Union	Felsenthal	Felsenthal Brick Co	Red surface clay	Stiff mud	Pallet and rack	4	Up	Do.
Washington	Prairie Grove[c]	Terpening Brick and Tile Co	Surface clay	do	Closed shed	6	do	Do.
	Springdale	J. W. Carter	3 feet surface clay	Hand	Open air		do	Common bricks.
	do	E. T. Caulde	Red surface clay	do	do	2	do	Do.
White	Beebe	Beam & Tidwell	do	Soft mud	do		do	Do.
	Judsonia	Judsonia Brick Co	do	do	do		do	Do.
	Searcy	J. Y. Woodson	do	do	do		do	Do.
Woodruff	Cotton Plant	H. F. Doyle						
Yell	Dardanelle	William Murphy						Do.

[a] Office at Story. [b] Office at Sutton. [c] Office at Farmington.

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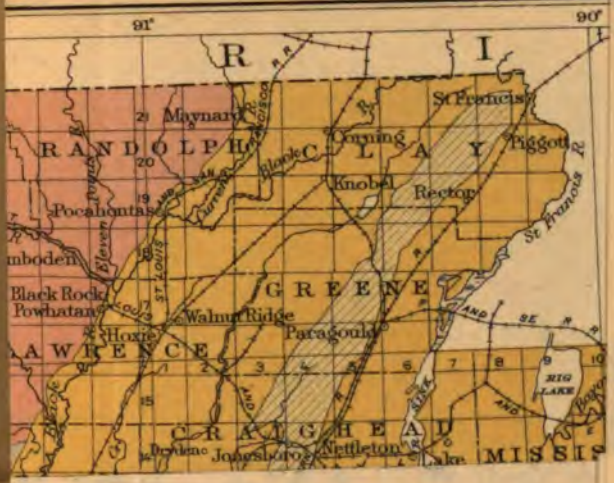

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L. C. Gratton

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 352

GEOLOGIC RECONNAISSANCE

OF A

PART OF WESTERN ARIZONA

BY

WILLIS T. LEE

WITH NOTES ON THE

IGNEOUS ROCKS OF WESTERN ARIZONA

BY

ALBERT JOHANNSEN

WASHINGTON
GOVERNMENT PRINTING OFFICE
1908

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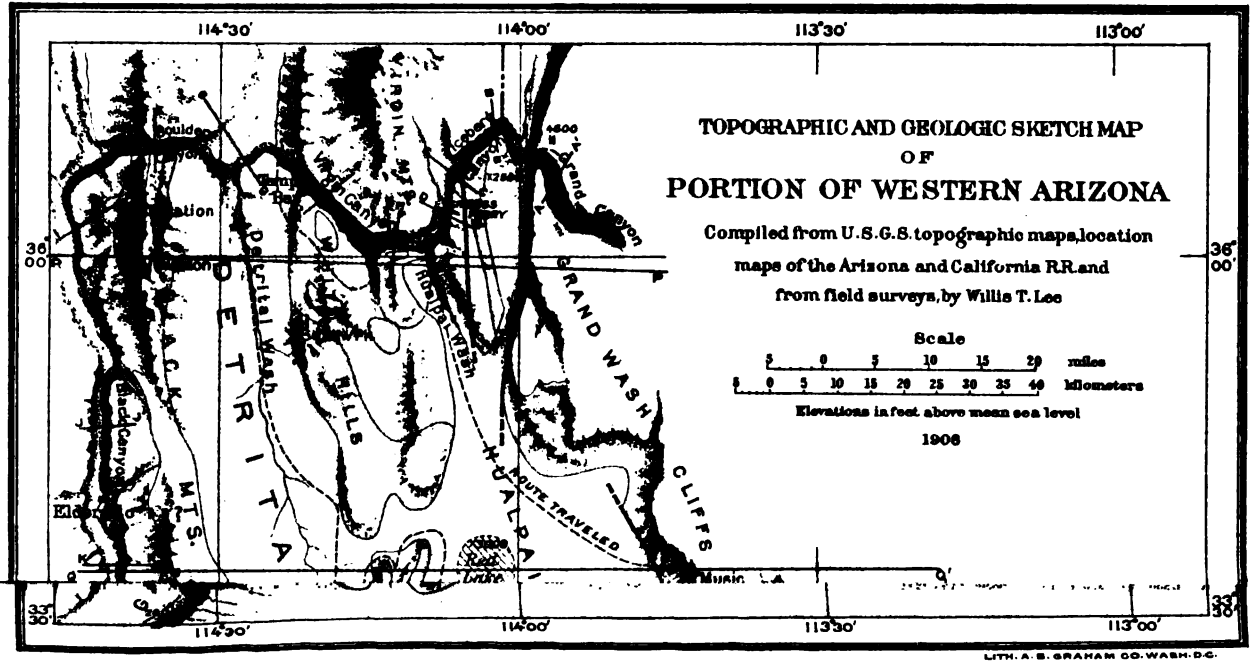

LEGEND

SEDIMENTARY ROCKS

Quaternary and Tertiary

Paleozoic
(Tonto and Redwall)

IGNEOUS ROCKS

Quaternary
(Basalt)

Tertiary
(Andesite and rhyolite)

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GEOLOGIC RECONNAISSANCE OF A PART OF WESTERN ARIZONA.

By WILLIS T. LEE.

INTRODUCTION.

Purpose of the investigation.—The investigations described in this bulletin were made in western Arizona under the general direction of Mr. N. H. Darton. The region examined lies mainly west of the high plateau and north of latitude 33° 30′.

The original purpose was to investigate the water resources of the region and the extent to which they might be developed. This necessitated an examination of the geographic features with special reference to irrigable lands and the possibilities of getting water to them, and of the geologic formations with reference to their bearing on questions of underground water. Conditions were found so unfavorable for water development in this region that the economic results of the work are unimportant, or at best have negative value. On the other hand, the region proves to be one of great geologic interest. Many significant features were observed, and their bearing on important geologic problems was noted, but want of sufficient time as well as the desert condition of the region made it impossible to follow out many of the most interesting lines of investigation.

Extent and character of the investigation.—The observations were made during rapid reconnaissance trips. In the summer and autumn of 1903 the Hualpai, Detrital-Sacramento, Big Sandy, Chino, and Aubrey valleys were visited, and Colorado River was examined from Needles, Cal., southward to Yuma, Ariz., the object of the river trip being to examine the geologic conditions at the various reservoir sites of the Reclamation Service along lower Colorado River. During the spring and summer of 1904 a more extended reconnaissance was made, including a river excursion from the mouth of Grand Canyon to Needles, Cal., and several overland trips shown on the accompanying map (Pl. I).

The amount of territory covered necessitated for the most part very general observations, and as the investigation was undertaken

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in the interests of water development the evident impossibility of development in certain places rendered it impracticable to make extended geologic examinations where such examinations would have been of great scientific interest. For these reasons the fragmentary data here presented might perhaps be of little use if they related to a region fairly well known, but so little is known either of the geology or of the geography of this region that the information, confessedly incomplete, will, it is believed, be of value to many persons.

The northern third of the region is covered by the early reconnaissance maps of the United States Geological Survey, and the geographic features are well known. Little has been done, however, toward accurately mapping western Arizona south of the thirty-fifth parallel. The maps heretofore published were found erroneous, especially in the locations of mountain groups and lines of drainage. It is not claimed that the map accompanying this bulletin is errorless, but in the southern part, where previously published maps have been most incorrect, this map is believed to be measurably accurate owing to data acquired by recent railway surveys and furnished for use in this bulletin by W. A. Drake, engineer of the Santa Fe Railway system.

The geologic formations were mapped where practicable, and their general distribution over the greater part of the region was determined. Data concerning their character and occurrence were collected as far as time would allow, and special attention was given to the recent geologic history.

During the investigation it became evident that changes of a physiographic nature have occurred in recent geologic times, which have produced notable results. Changes in surface elevation and configuration and in climatic conditions have resulted in periods of aggradation and periods of degradation during which nearly the entire region was affected. The evidences of these changes are found in such phenomina as recently formed canyons, filled valleys, aggraded plains, and the deflection of streams.

The chief economic results of the examination have to do with the development of both surface and underground waters. Attention is also called to the mining districts of the region, and certain possibilities of development of the mineral resources are pointed out.

Summary of previous knowledge.—Little information has hitherto been published regarding the geology of this region. In 1856 Jules Marcou's notes were published in the Pacific Railroad Reports,[a] in which he briefly describes the geologic features along the route traversed, including the igneous and granitic rocks of the Truxton Plateau, the detrital filling of the Big Sandy Valley, and the gneiss and

[a] Marcou, Jules, Pacific Railroad reports, vol. 3, 1856, p. 155.

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lava flows in the region of Williams Canyon. Again, in 1858, he makes brief mention of the region in his "Geology of North America."[a]

The first account of any considerable value is found in Lieutenant Ives's report on lower Colorado River, published in 1861. Part 3 of this report, by J. S. Newberry, describes the geology along the route traversed by the Ives expedition. Newberry ascended Colorado River to the mouth of the Virgin, and crossed the northern part of the region from Fort Mohave eastward to the Colorado Plateau. Later, Major Powell, in the course of his exploration of Colorado River, skirted the northern border as far as the mouth of the Virgin, and in the early seventies Gilbert and Marvine described its northern part in the final Wheeler reports.[b]

A few scattered references to the geology of the region are found also in various mining reports. In 1866 [c] Silliman visited certain mines near Fort Mohave, and described in a general way the volcanic rocks of Black Mesa. In 1863 Blake observed a deposit of iron ore near Planet, in Williams Canyon, and described the metamorphic strata with which it is associated.[d] This deposit, together with the copper deposits of the Planet district, have recently been described by McCarn [e] in a brief sketch of the geology of that locality, and Pratt [f] has described the occurrence of ore in the Socorro mine, near Harrisburg, Ariz.

GENERAL GEOGRAPHY.

RELATION TO SURROUNDING REGIONS.

Arizona is divided into three general geographic provinces,[g] known as the Plateau, the Mountain, and the Desert regions. The first province is well known through the writings of Powell, Gilbert, Dutton, Walcott, and others, as the Colorado Plateau; its western limit is very definitely marked in western Arizona by the Grand Wash Cliffs. Between the Plateau and the Desert regions is a mountainous belt comprising the second, or Mountain, region, which includes the greater part of the area described in this bulletin. The third, or Desert, region is mainly one of low-lying plains with more or less isolated mountain groups; it occupies the southwestern part of the Territory.

---

[a] Marcou, Jules, Geology of North America, 1858, p. 23.

[b] U. S. Geog. Surv. W. 100th Mer., vol. 3, pts. 1, 2, and 5, 1875.

[c] Silliman, Benjamin, jr., On some of the mining districts of Arizona: Am. Jour. Sci., 2d ser., vol. 41, 1866, pp. 289-308.

[d] Blake, W. P., Iron regions of Arizona: Idem, vol. 40, 1865, p. 388.

[e] McCarn, H. L., The Planet copper mines (Arizona): Eng. and Min. Jour., vol. 78, 1904, p. 26.

[f] Pratt, J. H., Gold deposits of Arizona: Idem, vol. 73, 1902, p. 795.

[g] Ransome, F. L., Description of Globe district: Geologic Atlas U. S., folio 111, U. S. Geol. Survey, 1904, p. 1.

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No definite line of separation can be drawn between the Desert and Mountain provinces in the area here described. In central and southern Arizona the distinction is well marked;[a] but in western Arizona the Mountain region, so prominent in the central part of the Territory, becomes a transition belt in which the descent of about 6,000 feet from the high plains of the Colorado Plateau to the low-lying plains of the Desert region of southern Arizona is accomplished through several mountain groups with gradually diminishing elevation. The transition becomes less marked northward until in northern Arizona the change in elevation is accomplished largely by fault scarps.

North of the area described Gilbert, in the Wheeler reports (and other geologists following him), makes but two general provinces, the High Plateau and the Great Basin, but states[b] that on account of an interlocking of characteristics along the borders their common boundary is not easily located. This division into two topographic provinces is a more natural one for northwestern Arizona than the threefold division of central Arizona. The basin ranges and broad gravel-filled valleys of Nevada extend southward into Arizona and bear the same general relations to the High Plateau that they do in southern Nevada and Utah.

TOPOGRAPHY.

General character.—The Colorado Plateau here enters into consideration only in so far as it forms the boundary of the area described. This bulletin is concerned chiefly with the low-lying area to the west.

In the Mountain region, south of the area described, the rocks have been deeply dissected by erosion, and great crustal movements have occurred. Near the escarpments bordering the plateau the mountains consist in some places of disturbed portions of the sedimentary formations of the plateau, let down to their present position by faulting. Mountains of this kind occur in the vicinity of Globe, Ariz.,[c] in the Tonto basin,[d] and within the region described near the mouth of Grand Canyon. In many places, especially at a distance from the edge of the plateau, sedimentary rocks are not found, and it is difficult to determine whether mountains composed entirely of crystalline rock are due to local elevation or are simply masses left by erosion during the general degradation of the region.

---

[a] Lee, W. T., Underground waters of the Salt River valley, Arizona: Water-Supply Paper U. S. Geol. Survey No. 136, 1905.

[b] Gilbert, G. K., and Marvine, A. R.: U. S. Geog. Surv. W. 100th Mer., vol. 3, 1875, p. 57.

[c] Ransome, F. L., Description of Globe district, Arizona: Geologic Atlas U. S., folio 111, U. S. Geol. Survey, 1904. Also Geology of the Globe copper district, Arizona: Prof. Paper U. S. Geol. Survey No. 12, 1903.

[d] Lee, W. T., Underground waters of the Salt River valley, Arizona: Water-Supply Paper U. S. Geol. Survey No. 136, 1905, p. 117.

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The mountain ranges throughout western Arizona, with a few notable exceptions, lie in general parallel to the border of the plateau. In general, also, the mountains become smaller and more completely isolated away from the plateau. In central Arizona, where the distinction between mountain and plain is most marked, rugged mountains extend from Mogallon Mesa to the Superstition Mountains, a distance of 70 miles, where they give place gradually through such isolated groups as the Phoenix Mountains, Estrella Mountains, etc., to the still smaller hills of southwestern Arizona. As the mountains become less prominent the valleys broaden and finally blend into a plain completely surrounding the isolated mountain groups. The topographic character of northwestern Arizona lies between these extremes, the area being about equally divided between mountain and plain.

Mountains.—The mountains of northwestern Arizona occur in four more or less distinct groups. The first consists of a series of cliffs at the eastern border of the region known as the Grand Wash, Cottonwood, Aquarius, and Yampai cliffs. The first three form a practically continuous escarpment, extending from Colorado River southward to Williams Canyon, a distance of about 125 miles. The Grand Wash Cliffs, extending from Colorado River to Music Mountain, a distance of about 50 miles, is composed of crystalline rock at the base, overlain by the sedimentary formations of the plateau region. At Music Mountain this escarpment divides, the lower or crystalline part continuing southward under the names of the Cottonwood and Aquarius cliffs and forming the edge of the Truxton Plateau, while the upper or sedimentary part recedes to the east, under the name of the Yampai Cliffs. With the lower group of cliffs may be included the Aquarius and Artillery mountains, which form the southward extension of the Aquarius Cliffs.

A second group, consisting of the White Hills, Cerbat, and Hualpai mountains and the Aubrey Hills, forms a broken range parallel to the cliffs at the west. The White Hills and the Aubrey Hills are inconspicuous as topographic features, but the two central sections are prominent. The Hualpai Mountains attain a maximum altitude of 8,266 feet in Hualpai Peak, and the Cerbat Mountains an altitude of somewhat more than 7,000 feet in Cherums Peak.

A third group, lying still farther to the west, is commonly known as the Black Mountain Range, and consists of the Black Mountains proper, Black Mesa, and the Mohave Mountains. This range is relatively low, except at its northern end, but is continuous from Colorado River southward to Sacramento Wash, where it is broken down for a few miles before attaining prominence again in the Mohave Mountains.

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The fourth group of mountains, situated south of Williams River, does not correspond with the other three groups in geographic position or in regularity of arrangement. In place of the parallel arrangement of north-south ridges just described, this group is made up of three large east-west ranges and three small north-south ranges. The Harcuvar and Harquahala mountains are about equal in altitude and are the loftiest and most massive mountains in central western Arizona. The other groups are less conspicuous, though the Buckskin Mountains are moderately prominent, particularly at their eastern extremity.

Valleys and plains.—Three distinct kinds of lowland occur: First, the valleys and canyons now containing running water, such as the Colorado and Williams valleys, including Big Sandy Wash and Santa Maria Canyon; second, old débris-filled valleys, such as the Detrital-Sacramento, Hualpai, and Big Sandy valleys; and third, plains eroded from hard rock or built up by flows of igneous rock, such as the Truxton Plateau. Extensive detrital plains, such as Cactus Plain, Ranegras Plain, etc., which occur south of Williams River, are probably débris-filled valleys similar to those farther north, but their character is not certainly known.

DESCRIPTIVE GEOLOGY.

ROCK FORMATIONS.

The rocks of western Arizona are mainly pre-Cambrian crystallines, Tertiary eruptives, and probably Quaternary sediments. Sedimentary formations of Paleozoic age occur only at the eastern margin of the area described. The igneous rocks are described by Albert Johannsen (see pp. 81–92), but many of the details upon which this general description is based may be found in the following sections.

PRE-CAMBRIAN.

The oldest rocks of the region consist mainly of granites and gneisses. (See p. 81.) Coarse-grained granitic rock giving little or no evidence of gneissoid structure is found in many places throughout northwestern Arizona. It occurs beneath the Cambrian sandstone at the base of the cliffs in the eastern part of the region, forms the central core of the Black Mountains, and constitutes the main mass of the Cerbat and Hualpai mountains. Gneiss occurs in many places, either in extensive masses, as at the southern end of the Hualpai Mountains and in the Aubrey Hills, or in restricted areas where local movements have taken place, as near Hualpai Wash, at the northern end of the region. At the mouth of the Grand Canyon the granite, which had obviously been exposed at the surface prior to the deposition of the Cambrian sediments, is prevailingly red to a depth of

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200 feet or more. A similar coloring of both the granite and the gneiss was noted in Black and Boulder canyons and in several places south of Williams River.

Metamorphosed sediments, consisting of quartzites, argillites, and limestones, occur in several localities in northwestern Arizona. These were observed in Virgin Canyon at the northern end of the region, in Williams Canyon, and in the Granite Wash Hills in the vicinity of Harrisburg. They are highly metamorphosed, faulted, tilted, and more or less included as blocks within the granites and gneisses. They were nowhere observed in contact with the Cambrian, but on account of their high degree of metamorphism and their intimate association with granites which, in the cliffs region, lie beneath the Cambrian sandstone, are here regarded as probably pre-Cambrian rocks.

CAMBRIAN.

According to the various writers who have described the Grand Canyon region, Cambrian rocks occur in Grand Canyon and are identical in character with those in the cliffs in the eastern part of the area described. They consist of a coarse-grained basal quartzite 80 to 100 feet thick, overlain by about 600 feet of yellowish-green arenaceous shale. The quartzite and shale together comprise the greater part of the Tonto formation of the Grand Canyon section.

CARBONIFEROUS.

Resting with apparent conformity upon the Tonto formation is the Redwall limestone (the Devonian of Grand Canyon described by Walcott[a] was not identified in the cliffs), which is 1,000 feet or more in thickness where examined.[b] From Music Mountain southward this limestone is separated more or less distinctly into an upper and a lower division. The upper part is massive, with little tendency toward separation into layers even in weathered surfaces. The lower part, although consisting mainly of limestone, is made up of distinct layers, often separated by thin seams of clay.

In Truxton Canyon two small collections of fossils were obtained from the Redwall limestone. These were examined by G. H. Girty, of the Geological Survey, who reports the following lists.

At Yampai, near the top of the exposed section, the following were obtained:

Derbya? sp.
Composita aff. C. subtilita.
Aviculipecten sp.
Aviculipecten sp.
Aviculipecten sp.
Myalina sp. aff M. meliniformis and M. congeneris.
Edmondia? sp.

[a] Walcott, C. D., Am. Jour. Sci., 3d ser., vol. 20, 1880, pp. 221-225.

[b] G. K. Gilbert's section at the mouth of Grand Canyon shows a thickness of 2,675 feet in the Redwall limestone.

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These fossils, according to Girty, indicate a Pennsylvanian or "Coal Measures" age.

Lower in the section, near Nelson, Ariz., Mississippian forms were obtained as follows:

Menophyllum excavatum.
Schuchertella inæqualis.
Spirifer centronatus.
Spirifer striatus var. madisonensis.
Straparollus sp.

Girty states that this is the Eomississippian fauna, which has a wide range over the West, correlating with the lower "Wasatch"[a] limestone of Utah, the Madison limestone of Yellowstone Park, and the Chouteau limestone of Missouri.

The Redwall limestone has been described by Gilbert[b] as consisting of "Upper Carboniferous" above and "Lower Carboniferous" below, and King[c] makes a similar division of the "Wasatch" limestone in Utah. It is probable that in the area here described the line of separation between the Pennsylvanian and the Mississippian is to be drawn between the upper massive and the lower laminated divisions of the Redwall.

TERTIARY.

Eruptive rocks.—If sediments of Triassic, Jurassic, or Cretaceous age were deposited in western Arizona, they were removed previous to the opening of the Tertiary period. The Tertiary rocks are principally effusive andesites and rhyolites, which occur in isolated mountain masses and in broad sheets having a maximum thickness of 3,000 feet or more. The oldest effusive rock is the andesite of the northern end of Black Mesa. (See p. 27.) It is a dark-colored porphyritic rock lying above the granite and beneath the rhyolites and later andesites.

The older andesite is overlain by extensive beds of rhyolitic ash, tuff, and flows, which extend over a large part of western Arizona, and which were in turn followed by extrusions of andesite. The rhyolites and younger andesites are closely associated and must at present be described together. (See pp. 83–87.) They are conspicuously exposed in the Black Mesa, White Hills, Kingman Mesa, and Aquarius Mountains, but extend eastward beyond the area mapped, and farther south occur in extensive masses in the Chocolate and Dome Rock ranges.

Some of the older basalt sheets of the region may also belong to the Tertiary, but this is not definitely known. They cut the rhyolites and andesites in dikes and overlie them in sheets. East of Chloride they

[a] Present usage of the Geological Survey restricts the name Wasatch to the Eocene formation. As soon as sufficient detailed work can be done, another name will be assigned to the Carboniferous formation.

[b] Gilbert, G. K., Final Rept. U. S. Geog. Surv. W. 100th Mer., vol. 3, 1875, pt. 1, p. 178.

[c] King, Clarence, Final Rept. U. S. Geol. Explor. 40th Par., vol. 1, p. 155.

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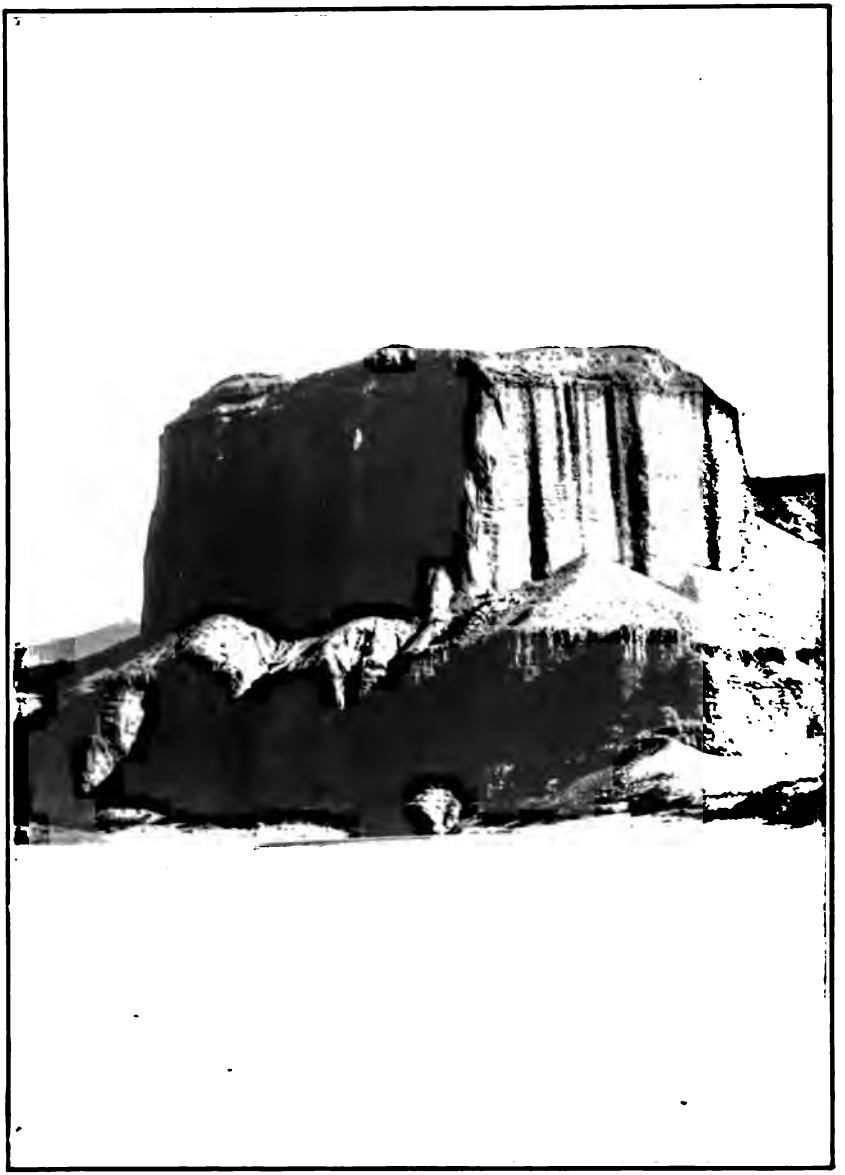

TEMPLE BAR CONGLOMERATE AT TEMPLE BAR.

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occur within the Detrital-Sacramento Valley, which was presumably excavated in late Tertiary time.

Greggs breccia.—The Greggs breccia, so called from Greggs Ferry, at the northern end of the region, is a name here given to a detrital formation filling the Grand Wash Trough and having an exposed thickness of about 1,400 feet. It is composed of coarse unassorted and poorly stratified material, consisting largely of blocks of crystalline rock, similar to the granite and gneiss of the Virgin Mountains to the west. Toward its top the detrital material is cemented with lime carbonate, and in places the upper 200 feet consists of travertine containing few rock fragments. This travertine is best exposed south of Colorado River and east of Greggs Ferry, where it caps conspicuous cliffs, which rise 1,400 feet or more above the river.

The formation contains no fossils, so far as observed, and its reference to the Tertiary is based largely on the physiographic evidence given in detail in the description of the Grand Wash Trough and later in the section on "Geologic history." Briefly stated, the accumulation of the breccia antedates the cutting of Grand Canyon, which apparently began either in the latter part of the Tertiary or at the beginning of the Quaternary.

QUATERNARY.

Temple Bar conglomerate.—Temple Bar conglomerate is a name here given to a sand and gravel formation having wide distribution in western Arizona. It occurs in the Colorado and other valleys of that region, filling the low places generally to an altitude of 3,000 feet or more. The conglomerate is typically exposed near the mouth of Virgin River at Temple Bar, from which it takes its name. At this point it consists of slightly consolidated sand and gravel exposed in nearly perpendicular cliffs (Pl. II), in which are included sheets of basalt.

Where exposed along the Colorado, the Temple Bar conglomerate is evidently a river deposit, but it merges laterally into deposits of angular mountain wash in some places, and possibly into lacustrine deposits in others. It rests unconformably upon the Greggs breccia and older formations, and is apparently equivalent in age to the widespread detrital accumulation filling the low places of the Southwest generally and forming the desert plains of Arizona and parts of southern California.

No fossils have been found in the conglomerate, and there are no means known at the present time by which it may be definitely correlated with other formations. In composition, geologic and physiographic relations, and general appearance it is similar to the Gila

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conglomerate described by Gilbert[a] from the Gila Valley; by Ransome[b] from the vicinity of Globe, Ariz.; by Lindgren[c] from eastern Arizona, and by the present writer[d] from the Salt River Valley in central Arizona. The greater part of the Temple Bar conglomerate, however, is not usually so well consolidated as the Gila conglomerate, although in places, especially where the older portions are exposed, it is as firmly cemented.

In constitution and general appearance the formation resembles the Lake Bonneville beds of Utah described by Gilbert[e] as Quaternary. The correlation, however, is based mainly on physiographic evidence, the discussion of which is included under "Geologic history," and, for the sake of clearness, is placed after the section on descriptive details.

Chemehuevis gravel.—Chemehuevis is here applied to a series of gravels that lie unconformably upon the Temple Bar conglomerate in the terraced bluffs along Colorado River from Grand Canyon to the Gulf. In the open valleys south of Black Canyon they form the conspicuous bluffs seen in characteristic development from Bulls Head southward. The name is derived from the Chemehuevis Valley, south of The Needles. The gravels are about 700 feet in maximum thickness, but occupy a measurably narrow belt along the river, having been deposited as valley filling during an aggrading stage of Colorado River. (See p. 65.) Their unconformable relations with the Temple Bar conglomerate and their unconsolidated condition render it probable that they are of late Quaternary age.

Basalt flows.—Included in the Temple Bar conglomerate in many places, and sometimes overlying that conglomerate, are sheets of basalt from a few feet to 800 feet in thickness, in some places occupying large areas. These are younger than the basalts which were described on page 16 as having perhaps been outpoured at the close of the Tertiary and which underlie the Temple Bar conglomerate.

GEOGRAPHIC AND GEOLOGIC DETAILS OF HIGHLANDS.

GRAND WASH CLIFFS.

Location.—The Grand Wash Cliffs, located in the northeastern part of the area described, form an escarpment extending from Music Mountain northward beyond Colorado River. They constitute the boundary between the High Plateau or Grand Canyon district to the east and the low-lying Basin region to the west.

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[a] Gilbert, G. K., U. S. Geog. Surv. W. 100th Mer., vol. 3, pt. 5, 1875, p. 540.

[b] Ransome, F. L., Geology of Globe copper district, Arizona: Prof. Paper U. S. Geol. Survey No. 12, 1903, pp. 47–51.

[c] Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, pp. 75–77.

[d] Lee, W. T., Underground waters of the Salt River Valley, Arizona: Water-Supply Paper U. S. Geol. Survey No. 136, 1905, pp. 111–114.

[e] Gilbert, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890.

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Topographic features.—The Grand Wash Cliffs are very precipitous, as shown in section *P-P'*, Pl. V, rising 4,000 feet or more above the plains to the west. The drainage of the plateau near the cliffs is northward to Colorado River, and the continuity of the westward-facing escarpment is broken by few canyons.

The lower or granitic portion of the cliffs, though not so nearly perpendicular as the upper or limestone portion, is steep, and the slopes meet the detrital surface of the Hualapai Valley at high angles. Numerous detrital cones have formed at the foot of the escarpment, but they are comparatively small. In a few places the cones join laterally, forming an alluvial slope, but in general the escarpment rises abruptly from the nearly level floor of the valley.

Rock masses.—At the mouth of Grand Canyon the cliffs are composed principally of Carboniferous limestone (Redwall) and Cambrian sandstone and shale (Tonto), with a little granite exposed at the base. In Music Mountain, at the southern end of the Grand Wash Cliffs, the same series occurs, but the granite is more extensively exposed, the base of the Tonto being about 4,000 feet higher than at the mouth of Grand Canyon.

The granite is coarse grained and is intersected by dikes and sheets of intrusive rocks which terminate abruptly at the contact between the granite and the overlying sandstone of the Tonto. This contact, as seen in the face of the escarpment, is a practically straight line and represents a base-leveled surface upon which the Cambrian sediments were deposited.

The sandstone at the base of the Tonto at the mouth of Grand Canyon is 80 feet thick and the overlying shale is about 600 feet thick. About 12 miles southwest of the mouth of the canyon, at the base of the tilted block through which Iceberg Canyon is cut, the sandstone is again 80 feet thick, but the overlying shale is only 200 feet. A few miles north of Music Mountain, in the pass occupied by the road from the Hualpai Valley to the plateau, the sandstone was found to be 50 feet thick and the overlying shale 300 to 400 feet thick.

The Devonian of the Grand Canyon region, described by Walcott,[a] was not identified by the writer in the Grand Wash Cliffs. The highest formation observed was the Redwall limestone, which forms the rim of the cliffs, and though more or less eroded, still has a thickness of 1,000 feet or more, according to locality.

COTTONWOOD AND AQUARIUS CLIFFS.

Location.—At Music Mountain the escarpment divides, the upper or sedimentary part receding toward the east and the lower or granitic part continuing southward under the names of the Cottonwood and the Aquarius cliffs. The Cottonwood Cliffs extend from Music

[a] Walcott, C. D., Am. Jour. Sci., 3d ser., vol. 20, 1880, p. 222.

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Mountain to Trout Creek, and are best observed in Truxton Canyon, through which the Santa Fe Railway descends from the high plateau to the lowlands farther west. The Aquarius Cliffs extend from Trout Creek southward to the Aquarius Mountains.

Topographic features.—The Cottonwood and the Aquarius cliffs are lower and less precipitous than the Grand Wash Cliffs. Alluvial cones and slopes are developed to some extent at the base of the Cottonwood Cliffs north of Truxton Canyon, but from that canyon southward to Signal the Big Sandy flows close to the cliffs and prevents the formation of cones.

The continuity of the escarpment formed by these cliffs is interrupted in several places by canyons, chief among which are Truxton, White Cliff, Trout, and Sycamore creeks. The canyons are narrow and steep and the streams torrential in character.

Rock masses.—The Cottonwood Cliffs are composed principally of granite, 2,500 feet of which is exposed near Hackberry. The granite is covered by a comparatively thin sheet of andesite which forms the cap rock of the cliffs and thickens southward, connecting with the great masses of igneous rock in the Aquarius Mountains.

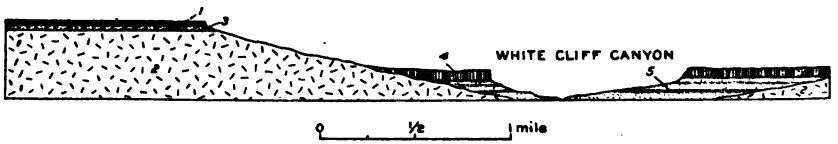

FIG. 1.—Sketch section across White Cliff Canyon, showing relation of the andesite of the Truxton Plateau to the younger basalt at the foot of the cliff. 1, Andesite flow; 2, granite; 3, andesite tuff; 4, basalt flow; 5, stratified volcanic ash.

In White Cliff Canyon the plateau is covered by andesite 200 feet thick, the lower half consisting of tuff and the upper half of a columnar flow. Near the mouth of the canyon a younger mass of volcanic rock occurs in an erosion embayment about 1,200 feet lower than the lava capping the cliffs. The younger mass is basalt and consists of several layers of ash, tuff, and flow. (See fig. 1.)

YAMPAI CLIFFS.

Location.—A series of irregular cliffs extends from Music Mountain in a general southeasterly direction to the southern end of the Juniper Mountains, where they turn northward, forming the western bluffs of the Chino Valley, which lies directly east of the area here described. These are locally known as the Yampai Cliffs.

Topographic features.—The Yampai Cliffs resemble the Grand Wash Cliffs in being precipitous and composed of hard limestone strata, but differ from them in being much more irregular in outline. They vary in altitude from about 6,000 to 6,700 feet and rise 1,000 or more feet above the Truxton Plateau. In their sinuous outlines, large reentrant angles, and detached outlying portions Yampai

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Cliffs exhibit the characteristic features of an erosion escarpment, the steep face being maintained by the hard Redwall limestone at the top.

Rock masses.—Pre-Cambrian granite occurs in the base of the cliffs. It was observed by the writer in four localities—at Music Mountain, in Truxton Canyon, near Cross Mountain, and at the southern end of the Juniper Mountains. As in the Grand Wash Cliffs, it terminates above in a base-leveled plain, upon which the Cambrian sediments rest.

The Cambrian rocks described continue uninterruptedly southward from the Grand Wash Cliffs, the basal sandstone being about 100 feet and the shale about 225 feet thick at the southern end of the Juniper Mountains.

The Redwall limestone continues southward as the highest formation of the cliffs, and on account of its superior hardness maintains the precipitous face. It thins southward, probably owing to erosion, until at the southern end of the Juniper Mountains it is only 450 feet thick.

The section near Nelson, in Truxton Canyon, yielded the fossils previously described, showing that the Redwall limestone is partly of Mississippian and partly of Pennsylvanian age. Although examined with considerable care, no fossils were found in the limestone at the southern end of the Juniper Mountains.

TRUXTON PLATEAU.

Location.—Lying between the Yampai Cliffs on the east and the Cottonwood and Aquarius cliffs on the west, is a comparatively level plain extending from Music Mountain southward to the Aquarius Mountains. The writer crossed it in two places near the northern end, as shown by the routes of travel delineated on Pl. I. In the vicinity of Truxton Canyon it is locally known as the Truxton Plateau, and this name may be used to designate the entire area.

Topographic features.—The plateau, which lies about 5,000 feet above sea level, consists of eroded granite, nearly covered with eruptive rock, which fills the depressions, leaving the higher granite points exposed above the lava. In other words, the Truxton Plateau is a lava-covered peneplain which has been slightly dissected by a few streams that have cut narrow canyons. Back from the edge of the plateau these are shallow, but they deepen rapidly as they near the cliffs to the west, a fact indicative of comparatively recent uplift.

Rock masses.—The rocks of the plateau are pre-Cambrian granites overlain by Tertiary rhyolite and andesite, together with basalt of more recent origin. The plateau was not visited south of Trout Creek, but, seen from a distance, the igneous rock apparently extends continuously southward to the great masses of rhyolite and andesite of the Aquarius Mountains.

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AQUARIUS MOUNTAINS.

Location.—The Aquarius Mountains, located in the east-central part of the region, form a group of considerable size at the southern end of the Truxton Plateau, and extend in a southeasterly direction across the course of Rio Santa Maria and Date Creek.

Topographic features.—South of the mouth of Deluge Wash the Aquarius Cliffs gradually lose their scarplike character and finally merge into the general westward slope of the Aquarius Mountains. These mountains were visited only at their southern and western extremities, but from the west at a distance they appear as lofty mountains, comparable in altitude with the Hualpai Mountains to the west, and the Harcuvar and Harquahala mountains to the south.

The southern part of the group is carved into rugged, irregular hills. Rio Santa Maria has eroded a narrow canyon deep into the lavas, and smaller streams have cut less deeply. Date Creek has cut through the end of the ridge, instead of following an apparently easy course a few miles farther south.

Rock masses.—The granite of the Truxton Plateau extends southward to the Aquarius Mountains, and was examined in Signal Canyon. The southern part of the group, however, is composed of andesites and rhyolites, presumably of Tertiary age. South of Santa Maria Canyon the mountains, 3,000 to 4,000 feet high, are composed of effusive rock, which has been dissected by erosion to a depth of about 3,000 feet.

Within valleys eroded in the Tertiary lavas small sheets of basalt occur, in some places capping gravels of probable Quaternary age, as in Signal Canyon (Pl. III, *A*), and in other places occurring within these gravels, as in Santa Maria Canyon near the mouth of Big Sandy Wash.

ARTILLERY MOUNTAINS.

Location.—The Artillery Mountains form a small group near the head of Williams River. They are separated from the Aquarius Mountains by Signal Canyon only, and are virtually an outlying group of those mountains.

Topographic features.—The Artillery Mountains are small and comparatively low, the only conspicuous peak being a sharp pinnacle of igneous rock, apparently a volcanic neck, which, on account of its altitude and pointed summit, is visible and easily identifiable from great distances. The rocks are deeply dissected by erosion on the east and south near Big Sandy and Williams rivers, but to the north and west the mountain flanks are buried by the detritus of the Big Sandy Valley.

Rock masses.—The main rock mass of the Artillery Mountains is coarse-grained granite, mineralized in places, although the mineral

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A. SIGNAL CANYON, AQUARIUS MOUNTAINS.

Showing lava-capped gravel and sand filling.

B. CHEMEHUEVIS GRAVEL NEAR BULLS HEAD.

Overlying granite at left. Showing upper and lower divisions of gravel.

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A. RHYOLITIC ASH NEAR KINGMAN.

B. DETRITUS AT MOUTH OF DELUGE WASH.

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prospects have not been extensively developed owing to the inaccessibility of the region.

Overlying the granite south of Artillery Peak occur thick masses of effusive rock similar in appearance to the older effusives of the Aquarius Mountains to the east, but separated from them by erosion. Quaternary lavas also occur in small quantities included in and overlying the gravels in Signal and Williams canyons.

WHITE HILLS.

Location.—The White Hills, located in the north-central part of the region described, are the southward continuation of the Virgin Mountains of southeastern Nevada, and are separated from them by Virgin Canyon.

Topographic features.—The White Hills consist of many more or less isolated peaks and groups of hills rising a few hundred feet above the plains on either side of them, and are inconspicuous as compared with neighboring highlands.

Rock masses.—Granite similar in general appearance to that beneath the Cambrian formation of the Grand Wash Cliffs occurs in these hills, and is more or less mineralized, several gold prospects having been developed in it. Quartzites and argillites, apparently of pre-Cambrian age, occur in the hills south of Virgin Canyon. The Tertiary rhyolites and andesites are found from Squaw Peak to the southern end of the White Hills, and occur as light-colored beds of tuff and ash and as flow sheets.

CERBAT MOUNTAINS.

Location.—The Cerbat Mountain range, about 30 miles long, lies south of the White Hills, between the Hualpai and the Detrital-Sacramento valleys.

Topographic features.—The mountains are high, attaining a maximum altitude of about 7,000 feet in Cherums Peak, and have been deeply eroded. At the southern end of the range they break down and merge into a dissected plateau.

Rock masses.—The Cerbat Mountains are composed mainly of granitic rock similar in general appearance to the pre-Cambrian granites of the cliffs region to the east. These are intersected and more or less completely surrounded by effusive rocks.

Along the western base of the range rhyolite and andesite occur at intervals, but are frequently eroded away or covered with wash. Near the southern end of the mountains they overlie the granite in extensive beds of ash, tuff, and flow, originally 1,000 feet or more in thickness. The igneous rocks are evidently due to a long series of eruptions, flows, and beds of tuff alternating (see Pl. IV, *A*), and both being cut by dikes and covered by younger effusives.

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These effusives are megascopically and microscopally the same as the rhyolites and younger andesites of Black Mesa to the west, and form a part of the lava sheet supposed to have once extended continuously across the Detrital-Sacramento Valley. At the northern end of the range sheets of olivine basalt occur at the crest of the ridge, tilted eastward. (See section *Q-Q'*, Pl. V.) In several places along the eastern base similar sheets occur, dipping steeply to the east and passing beneath the detrital filling of the Hualpai Valley.

Structure.—The eastward inclination of the lava sheets along the eastern base of the Cerbat Mountains suggests an eastward tilting of the surface similar to that shown in Iceberg Canyon to the north and in the Hualpai Mountains to the south (fig. 2).

HUALPAI MOUNTAINS.

Location.—The Hualpai Mountains are situated between the Sacramento Valley on the west and the Big Sandy Valley on the east, in the central part of the area described.

FIG. 2.—East-west section across Big Sandy Valley, showing the tilted Hualpai block and the unconsolidated gravel beds inclined toward the face of the Aquarius Cliffs. 1, Chemehuevis (?) gravel; 2, granite; 3, Temple Bar (?) conglomerate; 4, andesite.

Topographic features.—The range is about 35 miles long, with a general altitude of about 7,000 feet and a maximum altitude of 8,266 feet, attained in Hualpai Peak. The western slope is very precipitous down to an altitude of about 3,000 feet, where it meets the detrital plain of the Sacramento Valley at high angles. Along its base occur small flat-topped lava-covered hills, rising a few hundred feet above the surrounding plain. These are most numerous at the north, near the lava fields of the Kingman area, but extend southward nearly to the southern end of the range. Detrital material has accumulated in alluvial fans and slopes to some extent, but in general the steep mountain face meets the plain at high angles.

The eastern slope of the mountains is not so precipitous as the western. At altitudes of nearly 6,000 feet the crystalline rocks begin to disappear beneath a corrugated detrital slope of comparatively low gradient, which extends eastward to Big Sandy Wash, a distance of 10 to 15 miles. In this distance the descent is about the same as that attained in the western slope in a much less distance. (See fig. 2.)

At the southern end of the range the mountains cease rather abruptly, giving place to low isolated hills separated by broad passes occupied by the detrital accumulation of the plains. To the east are several comparatively small spurs and detached mountain groups, such as Owens Peak, Peacock Mountains, etc.

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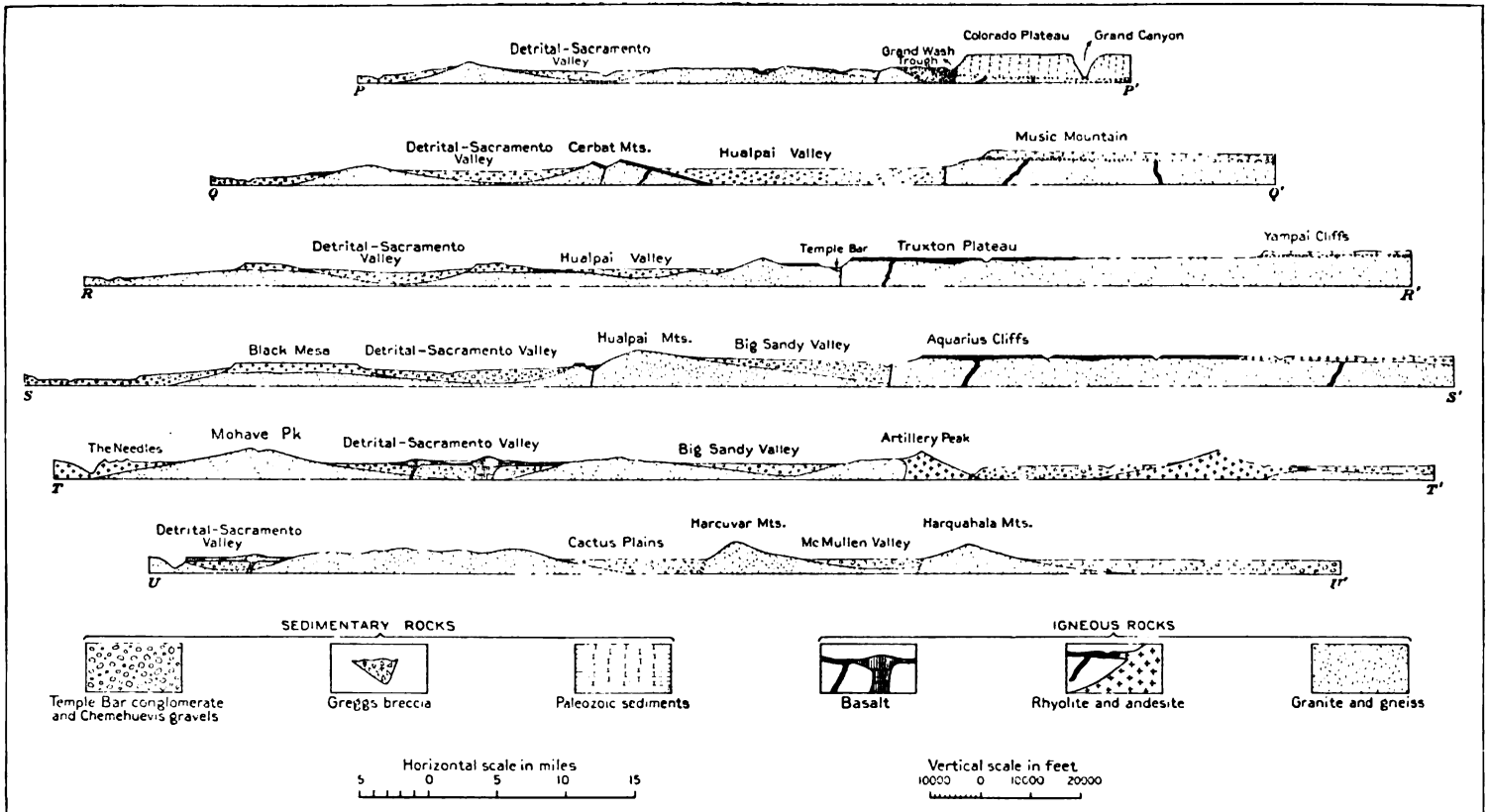

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Rock masses.—The Hualpai Mountains, so far as observed, are composed mainly of coarse-grained granitic rock, becoming gneissoid at the southern end of the range. They are highly mineralized in places, and dikes and quartz veins are numerous. At Cedar, near the summit of the range, mining operations have been successfully carried on for a number of years. The lavas capping the foothills to the west are outlying portions of rhyolites and andesites of the Kingman area (see p. 16), and the small masses in the Peacock Mountains are probably parts of the lavas covering the Truxton Plateau that have been let down to their present position by faulting. The detrital material of the eastern slope is part of the detrital accumulation described under the caption "Big Sandy Valley."

Structure.—The Hualpai Range was apparently formed by the upheaval and tilting eastward of a large crust block, the movement taking place along faults west of the range and at the Cottonwood and Aquarius cliffs. The evidence of block tilting in addition to that given of faulting along the cliffs rests on the steep, scarplike western face of the range, the high angles at which the mountain slope meets the surface of the Sacramento Valley, and the gently inclined débris slope of the eastern face.

AUBREY HILLS.

Location.—South of the Hualpai Mountains and lying between the Sacramento and Big Sandy valleys is a small group known as Aubrey Hills.

Topographic features.—The Aubrey Hills are low, rising but a few hundred feet above the plains on either side. They are separated from the Hualpai Mountains by a low débris-filled pass connecting the Big Sandy and the Sacramento valleys, and from the Buckskin Mountains by Williams Canyon.

Rock masses.—The rock at the northern end of the hills is granitic gneiss. In Williams Canyon occurs similar gneiss overlain by quartzite, argillite, and black metamorphic limestone. From a distance sheets of effusive rock were noted east of the hills, and dark-colored lava, probably basalt, was seen on their western flanks.

BLACK MOUNTAINS.

Location.—The Black Mountains, located in the extreme western part of Arizona, extend from the northern border of the Territory southward to Union Pass.

Topographic features.—The mountains are formed of three more or less distinct groups. The northernmost group, extending from Boulder Canyon southward to Eldorado Pass, a distance of about 15 miles, attains a maximum altitude of about 5,500 feet in Mount Wilson. From this peak the altitude diminishes northward to about

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3,000 feet at Boulder Canyon, and southward to about 2,000 feet at Eldorado Pass.

Mount Perkins, 5,500 feet high, is the center of the second group, which consists of a north-south ridge about 30 miles long. The third or southernmost group, about 4,500 feet in maximum altitude, consists of many small irregular hills extending eastward for a considerable distance into the Detrital-Sacramento Valley. The three groups form a continuous range, the apparent separation being due to accumulation of detritus, which fills the old valleys and covers the low-lying passes.

Rock masses.—The core of the Black Mountains consists of granitic rock. In Boulder Canyon coarse-grained crystalline rock occurs, as described by Gilbert,[a] overlain on either side by gneiss. In Pyramid Canyon, farther to the south, and in the hills east of this canyon the rock is granitic gneiss.

The older crystalline rocks of the range are overlain by extensive masses of effusive rock representing several periods of eruption. The oldest of the effusives, the andesite of the Gold Roads region, was not observed in Black and Boulder canyons, but in many places rhyolites and light-colored andesite similar to those overlying the dark-colored andesite of Gold Roads (see p. 27), rest upon the granites and gneisses. These are especially prominent in Black Canyon, where they are many hundreds of feet thick. They were observed near the river at the head of the Cottonwood Valley (section *K*, fig. 6), at the head of Pyramid Canyon, and at many places in the Black Mountains up to an altitude of 3,000 feet or more.

The next younger effusive rocks of the Black Mountains are basalts. They occur in dikes cutting the older rocks and in sheets overlying the rhyolites and younger andesites. North of Union Pass they were outpoured in the Detrital-Sacramento Valley, which had previously been eroded through the rhyolites and younger andesites.

BLACK MESA.

Location.—Black Mesa, about 35 miles long and 5 miles or more in width, is situated between the Colorado and the Sacramento valleys, in the central western part of the area described.

Topographic features.—The mesa is a remnant of a once extensive plateau having a general altitude of about 4,000 feet and a maximum at Mount Nutt of about 5,000 feet. A large part of the plateau has been eroded away and the remaining part deeply dissected by erosion. The bordering cliffs, although deeply incised, form a comparatively regular escarpment at the eastern margin of the mesa, rising 1,000 feet or more above the floor of the Sacramento Valley. The western margin is much more irregular owing to the greater erosion caused by

[a] Gilbert, G. K,. Final Rept. U. S. Geol. Surv. W. 100th Mer., vol. 3, 1875, pt. 2, p. 35.

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A. CASTLE-LIKE EROSIONAL FORMS IN BLACK MESA AT UNION PASS.

B. BASALT-CAPPED GRAVELS IN WILLIAMS CANYON.

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the downcutting of Colorado River. On this side are many more or less isolated outlying remnants of erosion, well shown on The Needles special map of the United States Geological Survey, which includes a small part of the southern end of Black Mesa (there called Ute Mountains). The most conspicuous of these outlying masses is Boundary Cone, 3,429 feet high—a sharp pinnacle rising 2,500 feet above the graded detrital slope which stretches from its base westward to Colorado River.

The rock of Black Mesa varies greatly in hardness, and erosion has carved out a great variety of topographic forms. In places where the mesa is composed of moderately uniform layers it is bordered by prominent cliffs of regular outline 1,000 feet or more in height. Where the rock varies in hardness within short distances, as at Union Pass, it is eroded into a great variety of castellated forms. (See Pl. VI, *A*.)

Rock masses.—The granite forming the core of the Black Mountains extends southward underneath Black Mesa, but it is exposed in few places, the mesa to a depth of 2,000 to 3,000 feet being composed mainly of effusive rocks. Granite porphyry was found at the base of Boundary Cone at the western edge of the mesa, and dark-colored andesite at the base of the cliffs at the northeastern extremity; the latter is best exposed in the vicinity of Gold Roads mining camp. The andesite rests upon the granite and is apparently overlain by rhyolite. Wherever observed, however, Black Mesa is composed mainly of rhyolitic tuff, breccia, and flow. The rhyolite is in turn cut by dikes of olivine diabase and overlain to some extent by sheets of basalt.

The granite underlying the rhyolite is penetrated by the well at Yucca and exposed at the base of the hills extending eastward into the Detrital-Sacramento Valley at the northern end of Black Mesa. The thickness of the effusive rock as determined at these points is about 3,000 feet.

MOHAVE MOUNTAINS.

Location.—The Mohave Mountains are located south of Black Mesa, between the Colorado and the Sacramento valleys. They consist of a massive central group, with a spur, known as The Needles, extending westward to Colorado River, and low unnamed hills extending southward to Williams River.

Topographic features.—The central group is subcircular in outline and about 5,000 feet high. It is deeply scored by erosion, and is apparently the remnant of a once much more extensive mountain mass.

The Needles are irregular pinnacles resulting from the erosion of the mass of effusive rock which formerly extended across Colorado River and was later dissected by that river in cutting its present

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canyon. The unnamed hills north and south of the central mass are remnants of erosion, now separated from the main peak by débris-covered passes.

Rock masses.—With the exception of The Needles, the rocks of the Mohave Mountains, so far as observed, are granite, gneiss, and later intrusives. The crystallines have been greatly fractured and faulted and contain many dikes and veins. The extrusive rock of The Needles overlies the crystalline complex on the eroded flanks of the Mohave Mountains, and is exposed in the canyon down to the river level. The thickness of the effusive rock as measured from the river bed to the summits of The Needles is about 2,000 feet.

HARCUVAR AND HARQUAHALA MOUNTAINS.

Location.—The Harcuvar and Harquahala mountains are located in the southern part of the area described, and extend from the eastern border of this area about 50 miles in a general southwesterly direction. They resemble each other in many ways and may be described together.

Topographic features.—The axes of these mountains lie in a direction practically at right angles to those of the other ranges of the region. Next to the Hualpai Mountains they are the loftiest in central western Arizona.

Both ranges are narrow, with precipitous slopes rising abruptly to altitudes of several thousand feet above the graded plain which surrounds them. The main range of the Harcuvar Mountains is broken at Cunningham Pass, and at either end the ranges break up into isolated hills. At the west end of these mountains a group known as the Granite Wash Hills exhibits a tendency to return to the north-south trend characteristic of the other ranges of western Arizona.

Rock masses.—The rocks were observed only in Cunningham Pass in the Harcuvar Mountains and near Harrisburg in the Harquahala Mountains, where they consist of a crystalline complex underlying and to some extent including masses of quartzite, argillite, and metamorphic limestone. A few miles south of Harrisburg, where these sediments were examined most closely, the strata stand nearly vertical.

BUCKSKIN MOUNTAINS.

Location.—The Buckskin Mountains, lying immediately south of Williams River, are virtually the southward continuation of the Aubrey Hills, being separated from them only by the narrow gorge cut by Williams River.

Topographic features.—The Buckskin Mountains are lofty at their eastern extremity, with a precipitous slope facing southward. The

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group is greatly eroded, the peaks being separated by comparatively low passes. The western part is composed of irregular hills formed by the dissection of a plateau of igneous rock, the general surface of which has an altitude of about 2,400 feet. The topographic features of the basalt-covered plateau near the mouth of Williams River are especially conspicuous (Pl. VI, *B*). The basalt of the surface is very resistant, and the underlying sand and gravel (see p. 54) is easily eroded, resulting in the formation of precipitous cliffs nearly 2,000 feet high.

Rock masses.—The rocks of the Buckskin Mountains consist of biotite granite, granitic gneiss and schist, metamorphic sediments, and effusive rocks. The gneisses and schists are conspicuously exposed in Williams Canyon, where they are horizontally laminated and fissile, suggesting the name Banded Canyon, by which Williams Canyon is locally known.

The crystalline rocks are overlain by quartzites, slates, and black metamorphic limestones. These are faulted and intersected by intrusive rocks, and contain deposits of copper and iron ore. A bed of hematite about 150 feet thick was observed near Planet.

PALOMAS AND DOME ROCK RANGES.

Location.—The Palomas and Dome Rock Mountains, in the southwestern part of the region, were not visited by the writer. Their form and location are taken from the railway-location map made by the Santa Fe engineers in locating the Arizona and California Railroad, furnished for this bulletin by the chief engineer, W. A. Drake. Little is definitely known of their topographic features or rock masses.

GEOGRAPHIC AND GEOLOGIC DETAILS OF VALLEYS.

COLORADO VALLEY.

GENERAL STATEMENT.

Colorado River was traversed by boat from the mouth of Grand Canyon southward to Yuma, a distance of about 325 miles. Throughout this course the rocks in which the valley is eroded are well exposed and geologic features of great variety are well exhibited. For convenience of description the valley is divided into sections, the important features being taken up in order from the mouth of the Grand Canyon downstream. Several diagrammatic sections across the valley are included with the descriptions in order to illustrate relations not adequately shown in the more generalized sections on Pl. V.

In the published accounts of Major Powell's explorations of the Colorado little is said of the river west of the mouth of Grand Canyon.

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The current is swift as far south as the mouth of Black Canyon, the fall being about 400 feet, or about 5 feet to the mile. There are several rapids of considerable size, formed by bowlders washed into the river from tributary canyons. The largest of these are: (a) Near Pierce Ferry in the Grand Wash Trough, caused by bowlders from the Greggs breccia entering from the south; (b) at the mouth of Grand Wash, caused by bowlders from this wash; (c) 3 miles east of the Nevada-Arizona boundary, caused by bowlders from a small wash entering from the north; (d) Red Granite Rapids, 3 miles west of the Nevada-Arizona boundary, at which point there is a long bowlder strainer[a] on the Arizona side which deflects the river sharply against the red granite on the Nevada side; (e) Hualpai Rapids, formed by the bowlders from Hualpai Wash; (f) Reverse Rapids, in Boulder Canyon; (g) Roaring Rapids, in Black Canyon.

MOUTH OF GRAND CANYON.

Colorado River emerges from the Plateau region about 7 miles east of the Nevada-Arizona boundary. The Grand Wash Cliffs, which form the western border of the plateau, rise to an altitude of about 4,500 feet, or 3,500 feet above the river. A few miles north of the rim of the canyon Shiwitz Plateau rises to an altitude of about 6,300 feet.

Grand Canyon is very narrow at its mouth (Pl. VII, *B*), and nearly perpendicular walls of Redwall limestone, sandstone and shale of the Tonto formation, and granite (see pp. 14–15) rise from the water's edge on either side. Springs emerge from these formations in many places and deposit carbonate of lime. The lower portion of the canyon walls is covered in many places with calcareous tufa and pendants of travertine. In some places the travertine projects irregularly, inclosing picturesque cavern-like chambers; in other places it forms basins built out into the river.

Massive beds of travertine were observed on both sides of the canyon at an elevation of 500 feet or more above the river. These may have been built out from the canyon sides by springs and later partly eroded away, but their horizontal bedding and location on opposite sides of the canyon at about the same altitude (see section *A*, fig. 3) indicate that they are probably remnants of a mass which formerly filled the canyon to a depth of several hundred feet. They are probably part of an extensive travertine formation having its greatest development near Hualpai Wash.

GRAND WASH TROUGH.

The Grand Wash Trough, lying between the Grand Wash Cliffs and Iceberg Canyon, is a depression formed by faulting and by the tilting

[a] "Strainer" is a term used locally to designate an accumulation of bowlders forming a porous dam in the river, through which the water finds its way as through a strainer.

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A. NORTH WALL OF CANYON IN GRAND WASH TROUGH.

B. MOUTH OF GRAND CANYON.

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of a large crust block. It derives its name from Grand Wash, which here enters the Colorado from the north. Its western limb consists of strata of the tilted block, and its eastern limb is the fault scarp of the Grand Wash Cliffs.

Not only are all the rock formations composing the Grand Wash Cliffs found in the tilted block in Iceberg Canyon, but strata younger than those in the cliffs are also present and pass beneath the river level with an eastward dip of 60° to 80°. Making no allowance for dip and considering only the altitude of corresponding strata in the walls of Grand Canyon and in Iceberg Canyon, the downthrow at the Grand Wash fault is about 5,000 feet. The strata of the block pass beneath the river level several miles west of the fault line. If the downthrow be computed from the dip of the strata and the distance from the fault line at which they pass beneath the river, the displacement at Grand Wash fault appears to be several times greater than the 5,000 feet in evidence at the surface.

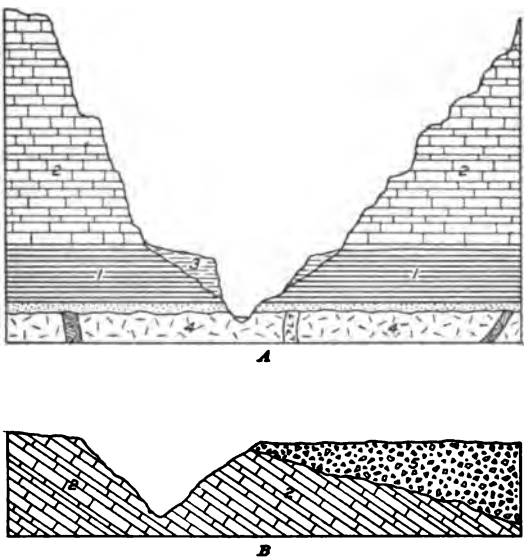

FIG. 3.—Diagrammatic sections across Colorado River. *A*, At mouth of Grand Canyon; *B*, in Iceberg Canyon. 1, Cambrian; 2, Redwall limestone; 3, travertine; 4, granite; 5, Greggs breccia.

The magnitude of the Grand Wash fault has long been recognized. Gilbert[a] states that the most profound dislocation of the plateau region has occurred at this fault, and Dutton,[b] in describing it, writes that "the plateau had its origin in a great fault along the crest of which the country east of it has been hoisted several thousand feet above the country on the west." Again he writes "It [the Grand Wash Cliffs] is a feature of the highest importance, since it is the boundary not only of the Grand Canyon district, but of the Plateau province itself. It drops the country on the west about 6,000 feet at a maximum." Huntington and Goldthwaite[c] have recently shown that the fault is traceable northward to

[a] Gilbert, G. K., Final Repts. U. S. Geog. Survey W. 100th Mer., 1873, pt. 1, p. 54.

[b] Dutton, C. E., Tertiary history of the Grand Canyon district: Mon. U. S. Geol. Survey, vol. 2, 1882, pp. 12, 19.

[c] Huntington, Ellsworth, and Goldthwaite, J. W., The Hurricane fault in the Toquerville district, Utah: Bull. Mus. Comp. Zoöl. Harvard Coll., vol. 42, 1904.

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the vicinity of Toquerville, Utah, a distance of about 80 miles, where it joins the Hurricane fault. The present writer traced it southward into the Hualpai Valley, where it apparently forks, the western branch reappearing west of the Hualpai Mountains and the eastern one following the cliffs.

The Grand Wash Trough is filled with Greggs breccia to an altitude of about 2,500 feet, or 1,500 feet above the river. Where the breccia was examined most carefully, in the bluffs south of the river about 4 miles east of Greggs Ferry, it was found to be composed of unassorted and poorly stratified débris consisting of angular rock fragments, principally granite, the largest having a diameter of 10 feet or more. Toward the top the fragments were cemented by carbonate of lime into a very resistant mass, forming the cap rock of certain conspicuous cliffs east of Greggs Ferry. The upper 100 feet or more of this capping stratum is travertine and is nearly devoid of rock fragments. Farther south the surface consists of the truncated edges of the upturned limestone block. (See section *P-P'*, Pl. V.)

The breccia of the Grand Wash Trough has been much more eroded north of the river than south of it. The breccia was not examined far from the river, but, judging from the size and character of the bowlders brought down by the washes, it is probable that the material in the midst of the trough does not differ greatly from that described from the cliffs at its western edge near Greggs Ferry.

The Temple Bar conglomerate also occurs in the Grand Wash Trough, appearing in many places at altitudes several hundred feet higher than the river, in depressions previously eroded in the older rocks. It is composed of sand and waterworn pebbles of quartzite, limestone, marble, etc., not distinguishable at the present time from the gravels derived from Grand Canyon. These are in places cemented by carbonate of lime into very resistant masses, forming nearly perpendicular cliffs 500 feet high. The travertine deposits just described within the canyon were probably formed at the same time.

The Temple Bar conglomerate of the Grand Wash Trough contains a thick sheet of basalt. The lava appears in the face of a cliff in Iceberg Canyon in the midst of the conglomerate, and in the Grand Wash Trough as a columnar sheet overlying the conglomerate. The relation of the Temple Bar conglomerate to the underlying sedimentary formations of the tilted block and to the overlying sheet of basalt is shown in Pl. VII, *A*.

The Greggs breccia, where exposed near the river within the Grand Wash Trough, is roughly stratified, and the strata are tilted eastward, the maximum dip observed being about 30°. The Temple Bar conglomerate is also locally disturbed, dips of 10° eastward being observed in places. At the base of the Grand Wash Cliffs the detrital

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material ends abruptly against the sedimentaries at the fault line, and is locally disturbed by movements apparently of recent date.

The somewhat complicated relations in the Grand Wash Trough may perhaps be made clearer by a brief statement of the events in the order of their occurrence. The formation of the Grand Wash fault and the tilting of the crust block were followed by a long period of erosion and deposition, which filled the trough with débris and planed off the upturned edge of the block, bringing the surface to a graded condition. The Colorado Plateau to the east was apparently at the level of this graded plain. Then followed a second period of faulting, in which great displacements occurred at the Grand Wash fault and minor displacements at several smaller faults to the west, accompanied by further tilting of the crust block and the elevation of the Colorado Plateau. This uplift of the plateau resulted in the inauguration of Grand Canyon, the river cutting directly across the Grand Wash Trough. The erosion proceeded until the canyon was cut to a depth practically the same as that it has at the present time. This was followed by deposition of gravels and of the Temple Bar conglomerate, and by eruptions of basalt, after which occurred renewed faulting and tilting of the limestone block, the Greggs breccia, and the Temple Bar conglomerate. Erosion again became active, and a second time the canyon was eroded to a depth greater than that it now has.

Later events, which are important farther downstream, are not conspicuously recorded in the Grand Wash Trough.

HUALPAI WASH.

Hualpai Wash enters Colorado River from the south and occupies a structural depression between the western edge of the limestone block on the east and the crystalline rocks of the White Hills on the west. This trough extends northward across the river and is there filled with gravel deposits, but their relation to other formations was not determined.

In Hualpai Wash a limestone several hundred feet thick occurs. In some places it is a massive, pink, compact rock resembling the Redwall limestone of the canyon section. Unlike that limestone, however, its character varies within short distances from a compact rock to a comparatively soft earthy substance, weathering with rough cavernous surface. In Hualpai Wash it rests directly upon an irregular surface of granite. In other places it abuts rather abruptly against previously existing granite cliffs, and contains fragments of the granite embedded within it. In still other places it apparently rests upon beds of sand and clay, although this observation was not satisfactory.

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The material is similar in character to the travertine capping Greggs breccia (section *C*, fig. 4), and to that occurring in beds 500 feet or more in thickness in the mouth of Grand Canyon (section *A*, fig. 3). It is apparently a travertine deposit belonging either to the Greggs deposits, let down to its present position by faulting (section *D*, fig. 4) or to the Temple Bar deposits, both of which are known to contain large beds of travertine. Its relation to the sedimentary rocks and to the underlying granite of the tilted block to the east is shown in the sketch sections in fig. 4.

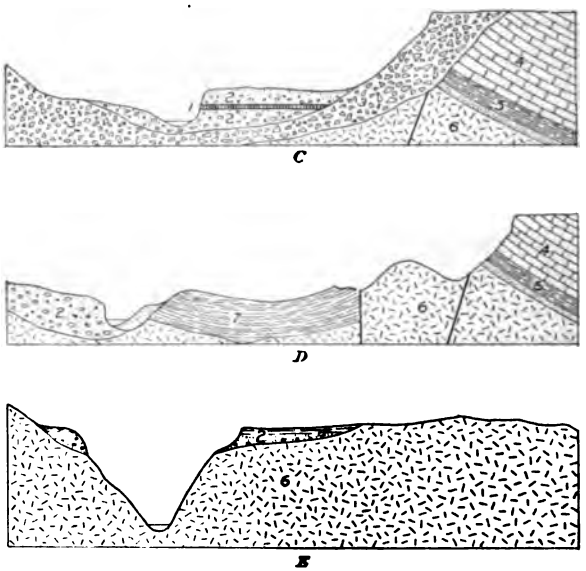

FIG. 4.—Diagrammatic sections across Colorado River. *C*, 4 miles east of Greggs Ferry; *D*, near Hualpai Wash; *E*, in Virgin Canyon. 1, Basalt; 2, Temple Bar conglomerate; 3, Greggs breccia; 4, Redwall limestone; 5, Cambrian; 6, granite; 7, travertine.

Within the canyon, resting unconformably upon Temple Bar conglomerate and the older formations at various points on either side up to an altitude of 150 to 200 feet above the water level, occur unconsolidated gravels. They are not conspicuous east of Iceberg Canyon, although some gravel beds in the Grand Wash Trough above high-water level may have been formed at the same time. Farther downstream they are conspicuously developed and are there known as the Chemehuevis gravel.

VIRGIN CANYON.

At the mouth of Hualpai Wash Colorado River enters a narrow rock gorge cut in the crystalline rocks of the Virgin Range. The canyon is about 5 miles long and from 1,000 to 1,500 feet deep, with walls rising steeply from the water's edge on either side.

High in the sides of the canyon walls occur remnants of light-colored, horizontally bedded material. (See section *E*, fig. 4.) These were not examined closely, but from a distance they have the same general appearance as the Temple Bar conglomerate characteristically developed at the same altitude a few miles farther west.

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A. TEMPLE BAR CONGLOMERATE RESTING UPON OLDER BRECCIA, NEAR TEMPLE BAR.

B. ENTRANCE TO BLACK CANYON.

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TEMPLE BAR.

Virgin Canyon widens westward as the river emerges from the crystalline rocks and enters the detrital beds. At Temple Bar the sand and gravel filling the Detrital Valley is exposed in vertical cliffs several hundred feet high. At the base of the cliffs is a coarse breccia exposed through a thickness of about 300 feet and composed principally of fragments of a rhyolite flow breccia cemented into a resistant mass. The cementing material is mainly carbonate of lime, but in some places it is silica and in other places oxide of iron. Springs issuing from this breccia are strongly charged with common salt and alkali, which gather as white incrustations about the springs.

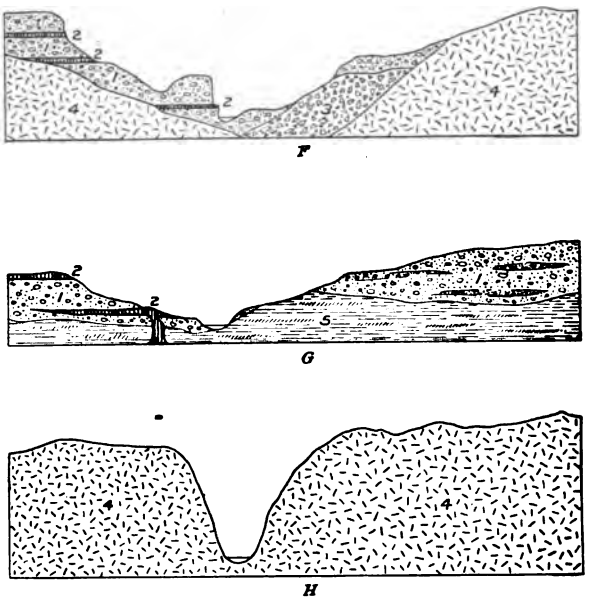

FIG. 5.—Diagrammatic sections across Colorado River. *F*, At Temple Bar; *G*, at Virgin River; *H*, in Boulder Canyon. 1, Temple Bar conglomerate; 2, basalt; 3, Greggs breccia; 4, granite; 5, salt and gypsum beds.

Resting unconformably upon this breccia and abutting against it, as illustrated in section *F*, fig. 5, occurs the characteristic Temple Bar conglomerate. The conglomerate consists of well-stratified sand and gravel (see Pl. VIII, *A*), and, although poorly consolidated, forms perpendicular cliffs hundreds of feet in height. Pl. II shows this conglomerate in one of its most characteristic exposures, where the cliffs rise abruptly from the water's edge to a height of 815 feet. A large number of equally conspicuous sand and gravel cliffs and monuments occur in the vicinity of Temple Bar, extending from the river level to altitudes of 2,000 to 2,500 feet.

Sheets of basalt occur at several horizons of the conglomerate. A shelf about 200 feet from the base (see Pl. II) is formed by one of these sheets of basalt, and other sheets occur at higher horizons (section *F*, fig. 5). South of the river a basalt sheet resting on top of the gravel beds may be younger than those included in them, or may be one of the included sheets exposed by erosion.

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The composition, stratigraphic relations, and general appearance of the older or cemented breccia suggest that it is probably a time equivalent of the Greggs breccia. The gravels above it form the Temple Bar conglomerate, which derives its name from this locality. The younger or Chemehuevis gravel is also present at Temple Bar, but is not conspicuous.

VIRGIN VALLEY.

Between Temple Bar and Boulder Canyon, a distance of about 12 miles, Colorado River crosses the old débris-filled valley which to the south of the Colorado is known as the Detrital-Sacramento Valley and to the north as the valley of the Virgin.

The filling of this old valley is apparently composed of two distinct formations, but their relation was not satisfactorily determined. The older one consists of alternating layers of sand and clay, and contains extensive beds of gypsum. Rock salt occurs in the Virgin Valley a few miles north of the Colorado, in beds similar to those containing the gypsum. These salt beds apparently lie beneath the gypsum, as shown by the salt well near the mouth of Virgin River, described by Gilbert.[a] The salt well is a crater-like depression about 300 feet across and 65 feet deep, situated in the midst of a level gravel plain. It is not connected with any surface drainage, and is evidently formed by a local caving of the surface probably due to the removal by solution of underlying beds of salt. It is filled with salt water to a depth of 15 to 20 feet.

The gypsum and gypsiferous clays are conspicuously exposed along the river, where they are deeply dissected over a large area locally known as the badlands of the Virgin. The presence of gypsum and salt indicates that this formation is not a part of the Temple Bar conglomerate, which overlies it with apparent unconformity (section *G*, fig. 5) and which does not contain gypsum or salt in its typical exposures so far as observed. The relation of the gypsiferous shales to the underlying rocks and to the overlying conglomerates was not satisfactorily determined. The stratigraphic position, however, suggests that this formation may be a time equivalent of the Greggs breccia.

BOULDER CANYON.

Boulder Canyon is a sharp gorge cut by Colorado River through the Black Mountain Range. It is about 5 miles long and 2,000 feet or more in depth, the walls rising steeply from the water's edge. The rocks exposed in the canyon are syenite, gneiss, rhyolite, and basalt. The basalts and their associated gravel deposits near the entrance to the canyon are faulted and tilted to some extent, and faults and open fissures occur in the canyon walls.

[a] Gilbert, G. K., Final Rept. U. S. Geol. Survey W. 100th Mer., vol. 3, 1875, pt. 1, pp. 109–110.

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Boulder Canyon is apparently younger than Virgin Canyon. The walls are but slightly eroded by lateral washes, although the open fissures and shattered condition of the rock in many places are favorable to the development of such; none were observed containing beds of the Temple Bar conglomerate, as is the case in Virgin Canyon.

LAS VEGAS WASH.

West of Boulder Canyon, and extending southward to the head of Black Canyon, the river flows through a débris-filled basin in which Colville and Las Vegas washes join the river from the north and west. Detrital beds resembling the Temple Bar conglomerate and containing sheets of lava are capped by a thick lava sheet in Fortification Hill at an altitude of 3,500 feet, or nearly 2,500 feet above the river (section *I*, fig. 6). The gravels are well stratified and are faulted and tilted in places.

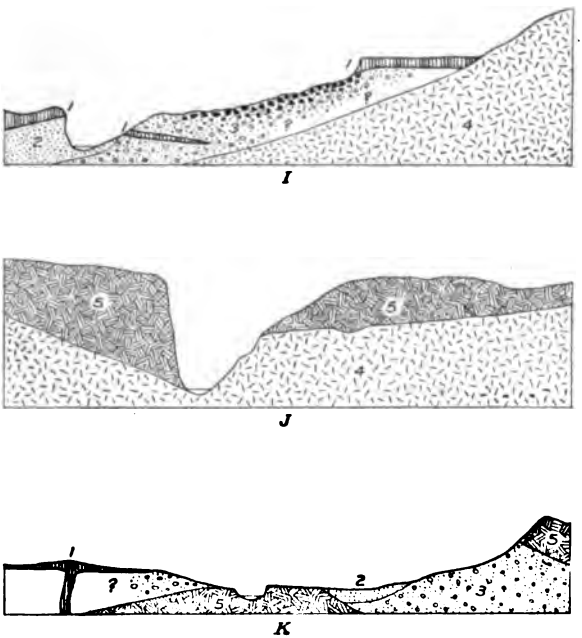

FIG. 6.—Diagrammatic sections across Colorado River. *I*, Near Las Vegas Wash; *J*, in Black Canyon; *K*, at Little Round Island. 1, Basalt; 2, Chemehuevis gravel; 3, Temple Bar conglomerate; 4, granite; 5, andesite and rhyolite.

BLACK CANYON.

A few miles south of Fortification Hill the river leaves the detrital basin and enters Black Canyon, a deep, narrow rock gorge about 18 miles long. The walls rise steeply from the water's edge (see Pl. VIII, *B*), and are composed to some extent of coarse crystalline rock, but mainly of massive rhyolite (section *J*, fig. 6). Black Canyon is very similar to Boulder Canyon in its general youthful appearance and in the absence of notable tributary washes and remnants of gravel beds.

COTTONWOOD VALLEY.

A few miles north of Eldorado Ferry the river emerges abruptly from Black Canyon into a broad open basin, the central part of

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which is known as the Cottonwood Valley. The basin is about 30 miles long and extends laterally from the Dead Mountains on the west to the Black Mountain Range on the east. At the northern

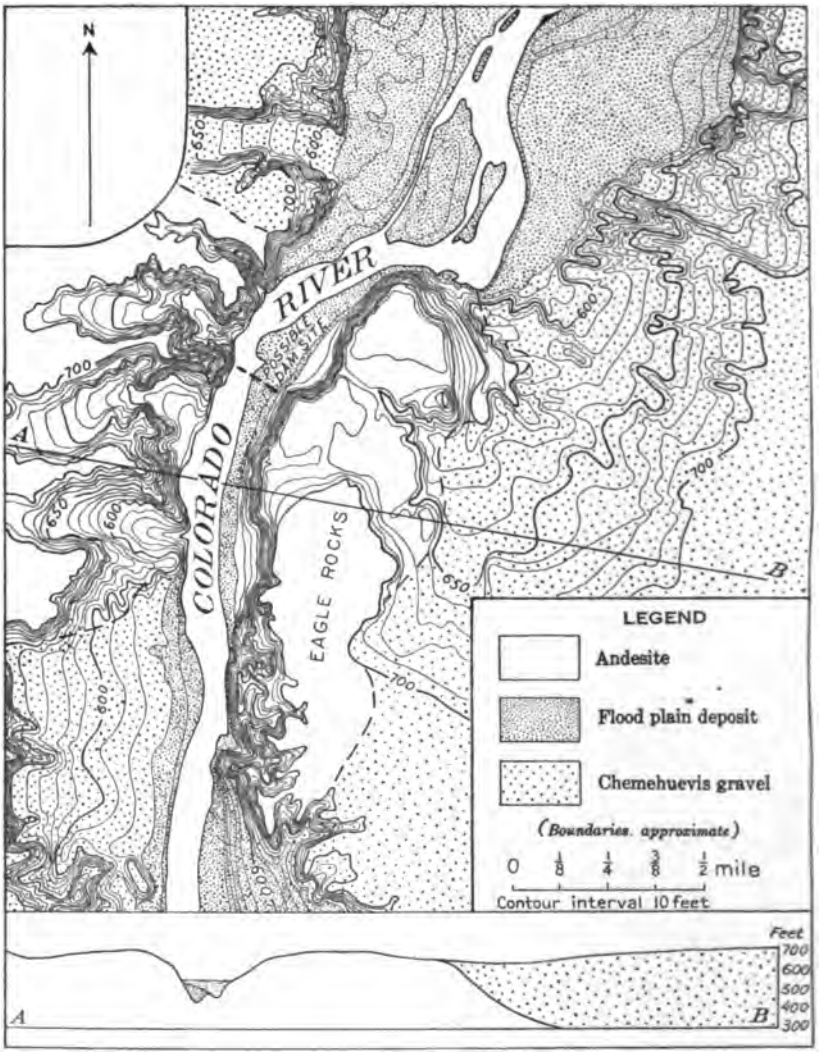

FIG. 7.—Map of a part of the Colorado Valley at the northern end of the Cottonwood Valley, showing an old gravel-filled channel at the right and the rock channel of the river at the left.

end of the basin gypsum-bearing beds similar to those near the mouth of the Virgin occur with an observed thickness of several hundred feet.

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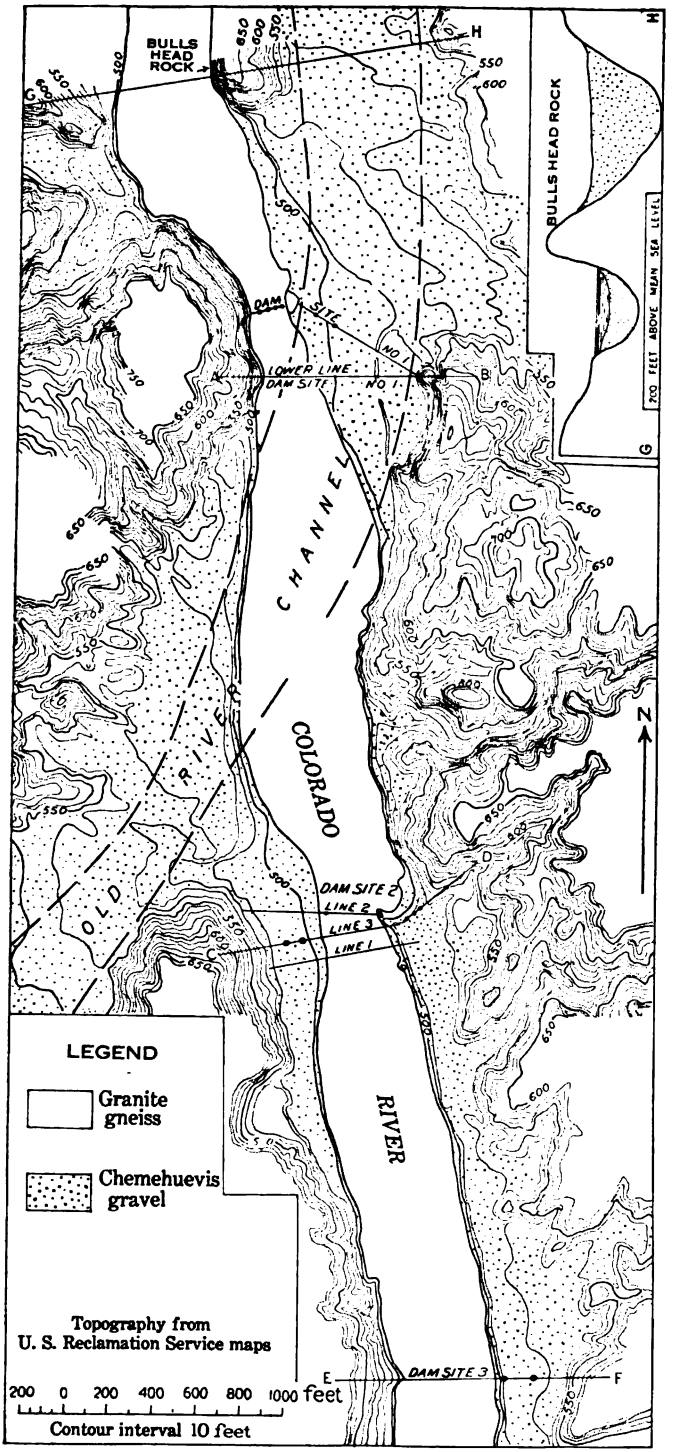

MAP AND SECTION AT SOUTH END OF PYRAMID CANYON, COLORADO RIVER.

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Near Round Island partly consolidated gravel beds similar in general appearance to the Temple Bar conglomerate and intersected by basalt dikes (see section *K*, fig. 6) occur above andesitic lavas. The gravels are well stratified, tilted steeply to the east, and extensively eroded. Horizontally bedded Chemehuevis gravel lies in depressions eroded in older upturned beds which in turn are younger than the andesites. For these reasons the older gravels are provisionally correlated with the Temple Bar conglomerate.

The Cottonwood Valley is the northernmost of a series of large basins which extend thence southward to the Gulf of California. The flood plain in the center of the valley is terminated laterally by bluffs of the Chemehuevis gravel. Between these bluffs and the mountains on either side are long corrugated slopes covered with angular rock débris or wash from the highlands. The slopes in the Mohave Valley were examined with more care than elsewhere, and are described in a following section. (See pp. 41–42.)

At Eagle Rock, near the southern end of Round Island, the river leaves the flood plain and flows through a narrow rock gorge about a mile long and 150 feet deep. The rock is andesite, and its relation to the gravel formations is shown in fig. 7. The gravel-filled channel to the east connects the Round Island Valley with the Cottonwood Valley proper. In other words, Colorado River, during one of its periods of canyon cutting, described under "Geologic history" (pp. 62–67), failed to reexcavate its old gravel-filled channel at Eagle Rock and cut a new channel in the rock west of the old one.

PYRAMID CANYON.

South of the Cottonwood Valley the granite and gneiss of the bordering mountains extend across the valley of the Colorado, and through these rocks the river has cut a canyon about 300 feet deep and 8 miles long. This is known as Pyramid Canyon, the name being derived from a pyramid-shaped rock near the northern end. East of the canyon, and separated from it by a narrow rock ridge (see Pl. IX), is an old channel filled with sand and gravel—Chemehuevis gravel—remnants of which occur 400 feet or more above the river, overlying and abutting against the granite and gneiss, as shown in Pl. III, *B*.

One of the proposed dam sites of the Reclamation Service is located at the southern end of Pyramid Canyon, near Bulls Head rock, the southern extremity of the rock ridge. On account of the investigations of the Reclamation Service in this vicinity much exact information is available. On this account the Bulls Head region is perhaps the best locality for the description and illustration of the late physiographic history of Colorado River. Unfortunately

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the detailed maps do not extend far enough northward to show to advantage the relation of the new rock channel to the old gravel-filled valley, but its southern end is shown in Pl. IX, and its relations are indicated in fig. 8. In Pl. X, *A*, a view of Bulls Head rock is presented, showing the river channel to the left and the gravel-filled valley to the right, as seen from the south. At intervals for several miles north of Bulls Head rock the ridge between the old and new channel is cut through by tributary washes, exposing such sections of the Chemehuevis gravel as that shown in Pl. III, *B*.

The old course was not so satisfactorily traced to the south. As shown on the map, it apparently crossed the present course of the river at a point where the gravels fill a depression similar to that at

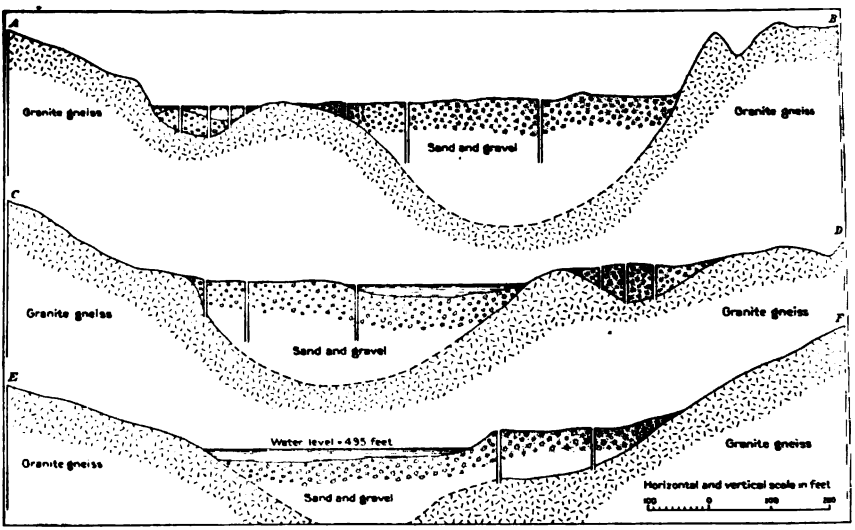

FIG. 8.—Profiles across Colorado River at the southern end of Pyramid Canyon, constructed from boring records. (For location see Pl. IX.)

the north, and connected with the extensive gravel deposits of the Mohave Valley to the south.

Although the river occupies a narrow rock channel in Pyramid Canyon, it does not flow upon a rock bed, as might be expected. Borings were made for the Reclamation Service in three localities across the river (see Pl. IX), and the gravel filling was found to be more than 100 feet deep. The probable profiles, as constructed from the boring records, are shown in fig. 8.

No distinction can be drawn with certainty between the old and new channels at the places where the borings were made. At the northernmost locality (section *A-B*, fig. 8) the channel at the left now occupied by the river, in which the gravels are about 50 feet deep, is apparently the new one, and that at the right, more than 100 feet

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A. COLORADO RIVER AND GRAVEL-FILLED VALLEY AT BULLS HEAD ROCK.

B. TILTED GRAVELS IN SACRAMENTO WASH.

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deep, the old one; but in the absence of soundings within the canyon north of Bulls Head, the depth of the new channel remains in doubt. Borings 100 feet deep in the older channel do not penetrate through the gravels.

A brief statement of the physiographic history of the river, as here recorded, may give a clearer understanding of the phenomena described. The river at some former time occupied the old course to the east (Pl. IX) and eroded its channel to a depth considerably below the present river level. Later the Colorado deposited the Chemehuevis gravel, filling its valley with sand and gravel to a level several hundred feet above the present bed. When the river again began to erode, it reexcavated the old valley throughout the greater part of its course, but in Pyramid Canyon, at Eagle Rock (described in the previous section), and at other places farther south to be described in following sections, it left its old course and cut rock gorges at one side.

MOHAVE VALLEY.

The Mohave Valley is a large basin extending from Bulls Head southward to The Needles, a distance of about 35 miles. The center of the basin is occupied by a broad flood plain having an area of about 50,000 acres. This is bordered on either side by terraced gravel bluffs, from which long, graded, alluvial slopes extend to the bordering mountains, joining the slopes at altitudes of 2,500 to 3,000 feet.

The rock masses in the Mohave Valley were examined principally east of the river. The rocks of Black Mesa to the east are mainly andesite and rhyolite, resting upon granitic gneiss. Overlying these older rocks occurs a formation of partly consolidated sand and gravel, which in composition and general appearance resembles the Temple Bar conglomerate. It is exposed in steep cliffs in the washes of the alluvial slope, and the strata are generally nearly horizontal. In some places, however, the layers are faulted and tilted (see Pl. X, *B*). These stratified sands and gravels are covered with coarse rock débris, due partly to wash from the hills and partly to surface concentration of the coarser material of the conglomerate.

Resting upon this formation and occupying spaces eroded in it is the Chemehuevis gravel, forming conspicuous terraces, three of which are prominent and traceable continuously for considerable distances; in some places five are distinguishable. The lowest is about 50 feet above the river, and is represented by the broad shelf upon which old Fort Mohave stands; the second is about 100 feet higher, and the others occur at intervals of 50 to 100 feet.

The Chemehuevis gravel varies considerably in character from place to place from beds of large, well-rounded pebbles to those of

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fine sand and clay. At the northern end of the Mohave Valley, near Bulls Head, there are two distinct divisions of the gravel. (See Pl. III, *B*.) The lower division consists mainly of well-stratified and firmly packed sand and silt; the upper of stratified but very loose sand and gravel. The two divisions appear to be perfectly conformable, and the difference in character is probably due to some change in the river, such as an increase in its carrying power, enabling it to bear the finer material away and deposit only the coarser material; or to a change in course, bringing the gravel-bearing current over what had formerly been a flood plain.

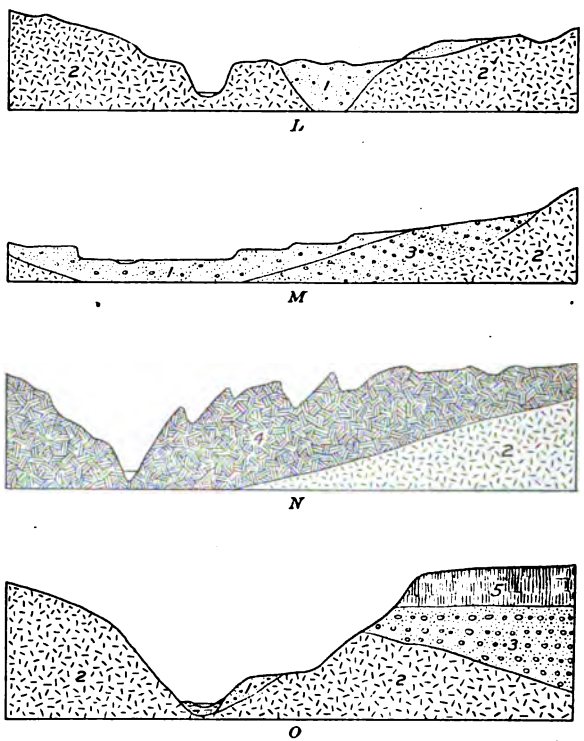

FIG. 9.—Diagrammatic sections across Colorado River. *L*, Pyramid Canyon; *M*, in the Mohave Valley; *N*, in the Needles Mountains; *O*, at the mouth of Williams River. 1, Chemehuevis gravel; 2, granite; 3, Temple Bar conglomerate; 4, eruptive; 5, basalt.

The gravels in the old channel east of Pyramid Canyon were examined with considerable care and found to consist of limestone, marble, sandstone, and metamorphic and igneous rocks of great variety. Many of the limestone pebbles have beautifully etched surfaces, which Gilbert[a] describes as "carved with a network of vermicular grooves into a most beautiful arabesque design." These etched pebbles were observed in the Chemehuevis gravel throughout the region described.

THE NEEDLES.

South of the Mohave Valley occurs a mass of eruptive rock resting on the flanks of the Mohave Mountains (section *N*, fig. 9), and characterized by sharp pinnacles of erosion, from which the group has been called The Needles. Mohave Canyon, about 8 miles long, has been cut in this eruptive mass to a depth of about 2,000 feet. In gen-

[a] Gilbert, G. K., U. S. Geog. Surv. W. 100th Mer., vol. 3, 1875, pt. 1, pl. 9 and p. 83.

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eral the rock walls rise abruptly from the water's edge, but in some of the more open spaces sand and gravel of the Chemehuevis formation occur to a considerable height above the river.

At Big Bend, 4 miles south of Mellen, the river leaves a comparatively open portion of the canyon and turns abruptly to the west into a narrow rock gorge having an old gravel-filled channel, which continues southward in the normal direction of the river (fig. 10).

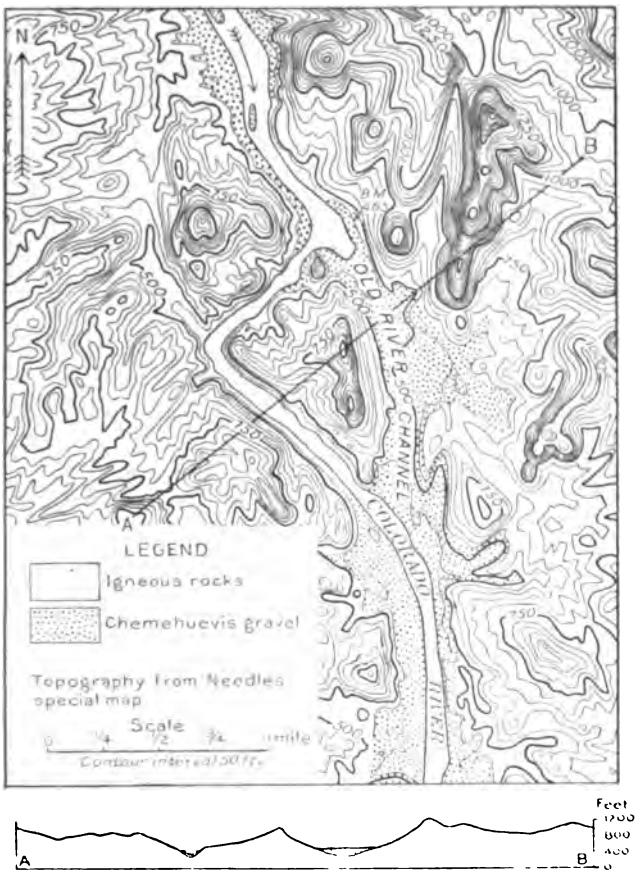

FIG. 10.—Map of Great Bend in Mohave Canyon, showing relation of an old débris-filled channel to the present course of Colorado River.

The phenomena here are similar to those just described from Pyramid Canyon, except that the new course is shorter and the gravel filling of the old one has been more nearly eroded away than in Pyramid Canyon.

CHEMEHUEVIS VALLEY.

The Chemehuevis Valley extends from The Needles to the mouth of Williams River, a distance of about 25 miles, and is narrower than

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the other basins along the course of the river. The Chemehuevis gravel, which derives its name from this valley, occurs here in characteristic development, lying unconformably upon older and partly consolidated gravels. The older gravels are horizontally bedded in some places but in others are faulted and highly inclined.

The relation of the Chemehuevis gravel to the older conglomerate was noted at several points along the river. In some places the older gravels are undisturbed beneath the Chemehuevis, the two being separated by an unconformity of erosion (section *A*, fig. 11). In other places the older gravels are upturned, eroded, and overlain by horizontally stratified Chemehuevis gravel (section *B*, fig. 11). In still

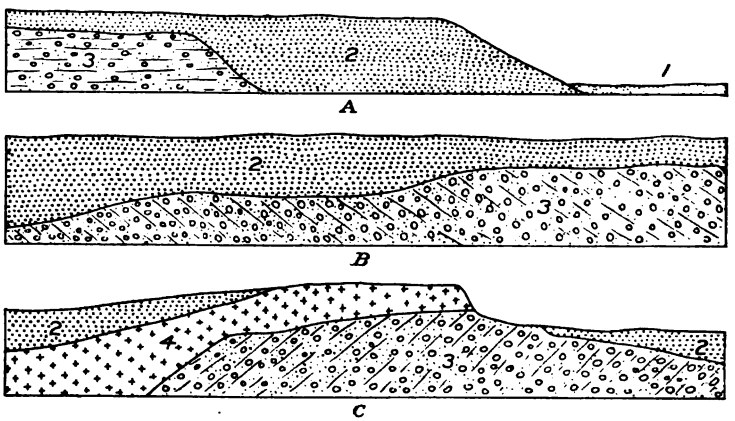

FIG. 11.—Relations of gravel formations to each other and to igneous rock in the Chemehuevis Valley. *A*, The three gravel formations horizontally bedded but separated by unconformities of erosion; *B*, the older conglomerate tilted, eroded, and overlain by horizontally bedded younger gravels; *C*, the older gravels tilted, intersected and overlain by lava, eroded, and again overlain by horizontally bedded younger gravels. 1, Flood-plain deposits; 2, Chemehuevis gravel; 3, Temple Bar (?) conglomerate; 4, igneous rocks.

other places the older gravels are tilted, intersected by lava, eroded, and overlain by the Chemehuevis gravel (section *C*, fig. 11).

The older gravels apparently overlie rhyolite and andesite, and at one point a stratum of rhyolitic ash occurs within them. They vary greatly in character from place to place from sandy clay to a breccia with granite bowlders 4 feet in diameter. In general appearance they resemble the Temple Bar conglomerate, and are provisionally correlated with it. This conglomerate is apparently the one which Newberry[a] in the Ives report referred to the Tertiary.

AUBREY CANYON.

Near the southern end of the Chemehuevis Valley the granite of the bordering mountains approaches the river, and at the mouth of Williams River the Colorado enters a narrow canyon, the walls of

[a] Newberry, J. S., Report upon the Colorado River of the West by Lieut. J. C. Ives, pt. 3, 1861, p. 29.

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which are composed of granite overlain by eruptive rock (section *O*, fig. 9). The eruptives west of the canyon were not examined closely, but resemble in general appearance the rhyolite and andesite to the north and the great masses of similar rock composing the Chocolate Mountains to the south. The eruptive rock east of the river is the basalt which caps the Temple Bar conglomerate, as described and illustrated from Williams Canyon (fig. 16).

East of Aubrey Canyon, and exposed in the bluffs of Williams Canyon (see p. 54), is an old valley filled to a depth of about 1,000 feet with the Temple Bar conglomerate and covered with 800 feet of basalt. Aubrey Canyon is younger than this gravel-filled valley, having been cut through the basalt sheet covering the Temple Bar conglomerate.

The rock channel in Aubrey Canyon has been cut to a considerable depth beneath the present river level, and filled with sand and gravel. Borings made for the Reclamation Service near the head of the canyon failed to reach bed rock at a depth of 75 feet. In the open basins the river is building flood plains, and the sediment accumulated within the canyon evidently corresponds with that in the open basins, but the maximum depth of this most recent deposit is nowhere indicated.

Here, as elsewhere along Colorado River, there is abundant evidence of a complex physiographic history. A broad valley, described elsewhere as the Detrital-Sacramento Valley (see p. 52), was formed east of Aubrey Canyon and filled to a depth of 1,000 feet or more with sand and gravel—the Temple Bar conglomerate. This was covered with 800 feet or more of basalt, and a new canyon was later eroded west of the old one (section *O*, fig. 9). Still later this canyon was filled with several hundred feet of sand and gravel—Chemehuevis gravel—which were partly carried away by renewed erosion that cut the canyon to a depth lower than the present river level. This channel was in turn filled to its present condition.

GREAT COLORADO VALLEY.

The Great Colorado Valley was examined only in the immediate vicinity of the river during a somewhat hurried excursion by boat, but the data obtained are supplemented to some extent by the investigations of the Reclamation Service. The valley is the largest of the basins through which Colorado River flows, extending, with varying width, from Aubrey Canyon southward to the Chocolate Mountains, a distance of about 75 miles. The Riverside and Halfway mountains form a partial boundary on the west, and the Dome Rock and other mountains on the east; but between the mountain groups occur broad grades, such as the Cactus Plain.

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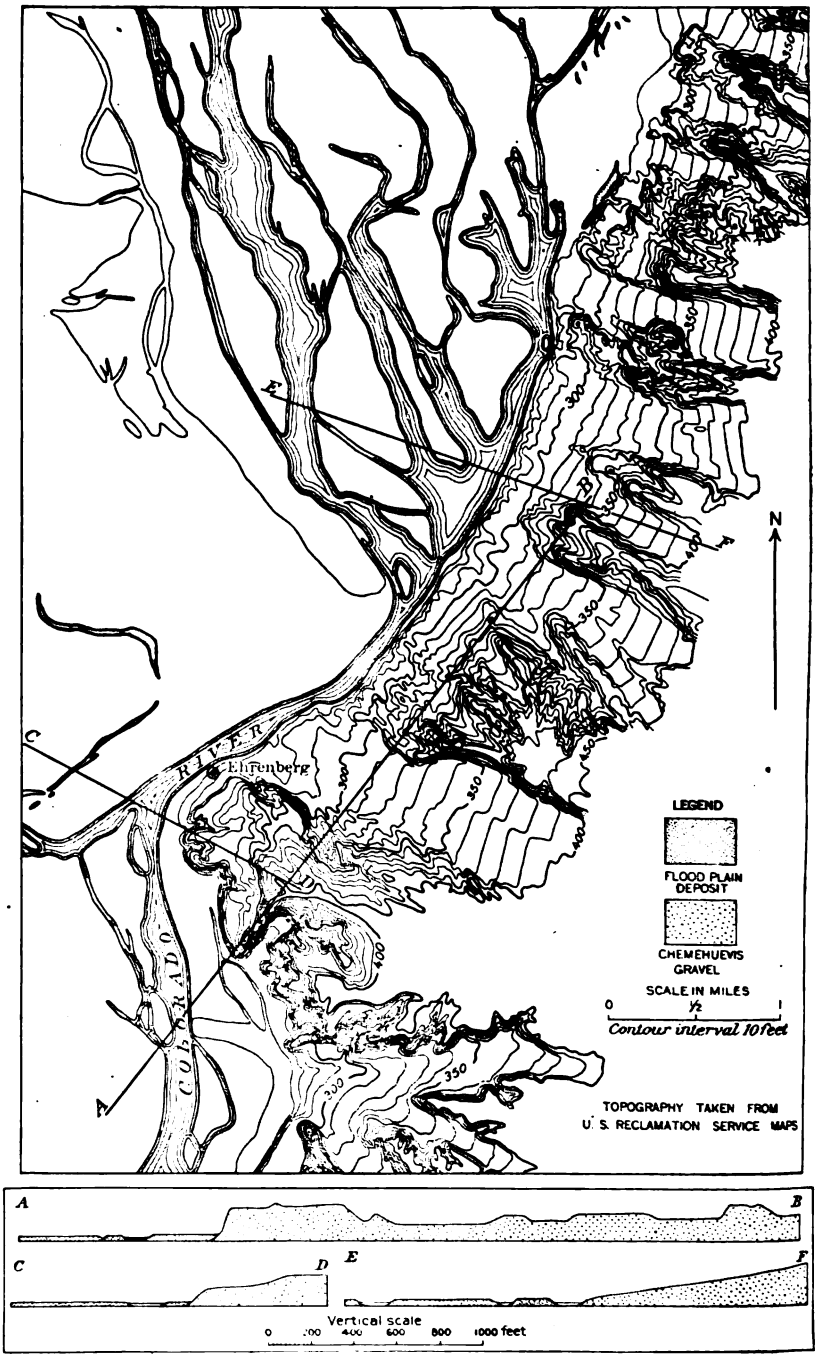

FIG. 12.—Map and sections of a part of the Great Colorado Valley, illustrating the lateral migrations of the river, the relation of the flood plain to the bluffs of the Chemehuevis gravel, and the corrugated slopes at the margins of the valley.

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Like the other basins described, the Great Colorado Valley contains gravels representing three distinct epochs of accumulation. The oldest, interpreted as belonging to the Temple Bar conglomerate, was observed near the northern end of the valley, where it is overlain by lava, as at Headgate Rock. Farther to the south, in the middle of the valley, it was not identified.

The younger or Chemehuevis gravel occurs throughout the Great Colorado Valley in conspicuous terraced bluffs. The beds vary much in composition, from a sandy silt to coarse gravel, the finer material greatly predominating. The sand is regularly stratified, cross-bedded, and not distinguishable in physical character or composition from the beds forming at the present time over the flood plain. The Chemehuevis gravel extends for an undetermined distance back from the terraced bluffs, and form corrugated slopes illustrated in fig. 12. The washes entering at the sides of the valley have steeply graded floors, often extending back many miles toward the hills, and are terminated laterally by nearly perpendicular walls. These floors often join laterally, forming wide graded slopes.

From the foot of the gravel bluffs (fig. 12) and extending throughout the valley with a maximum width of 12 miles and a length of 75 miles are flood plains building up by the deposition of sand and silt. Over this great area Colorado River is continually shifting its channel, sometimes gradually by slow cutting and filling and sometimes suddenly by turning through one of the numerous abandoned channels.

The annual floods carry immense quantities of silt, which they spread over the flood plain, building it up with great rapidity. Where the caving banks of the river expose vertical sections it was noted that the roots of living arrow weeds had been buried to a depth of 6 feet or more. In other words, there have been accumulations of silt 6 feet or more in depth during the life of this shrub. The material is well stratified, sometimes with horizontal lamination, but often showing a conspicuous oblique lamination similar to that found in the Chemehuevis gravel. Much of the silt is very fine and is held in suspension for a long time. When deposited in thick beds it dries and cracks in columnar form, some of the columns being 2 to 3 feet in diameter and separated by cracks several inches wide and 2 feet or more deep.

CHOCOLATE MOUNTAINS.

South of the Great Colorado Valley, for a distance of about 30 miles, Colorado River flows in a canyon or narrow valley through the Chocolate Mountains—a name applied generally to a complex group consisting of the Spire Range, the Picacho group, the Castle Dome Mountains, and the Purple Hills.

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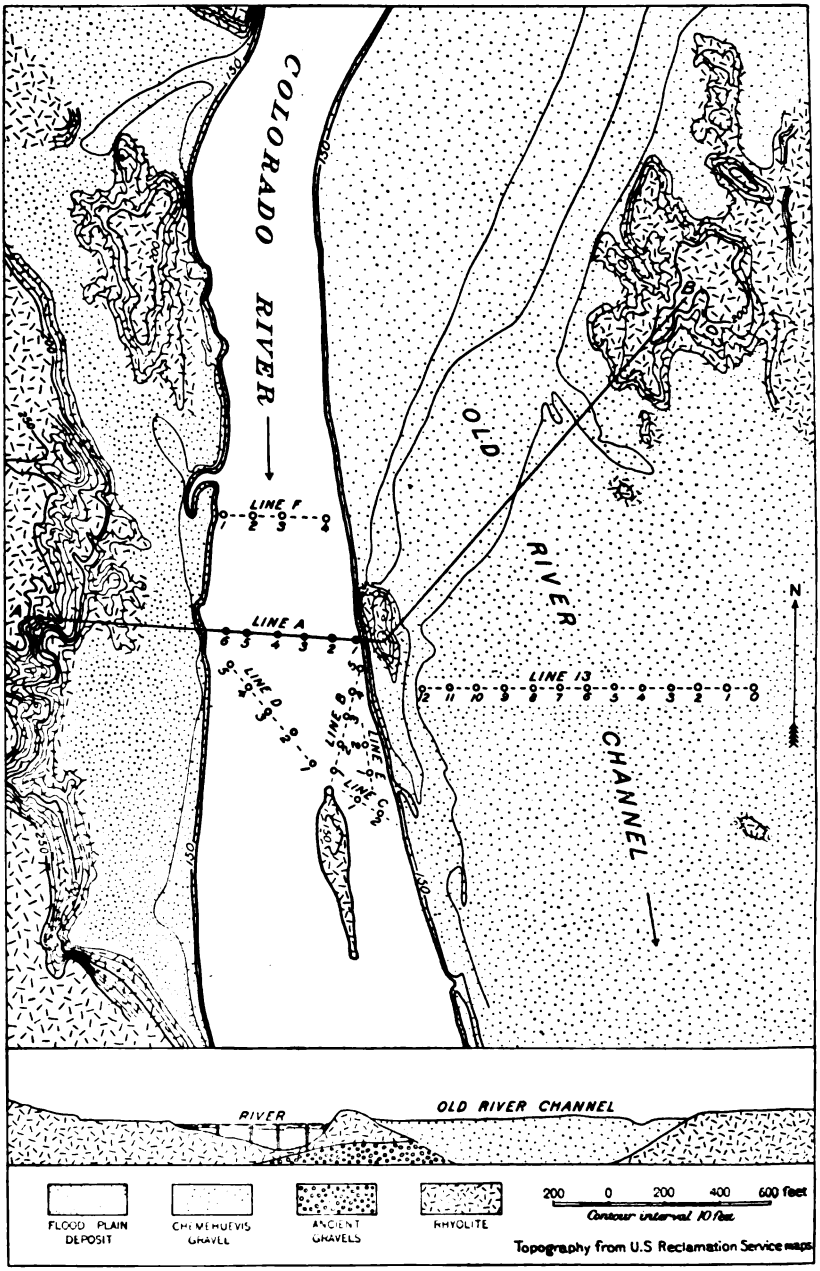

FIG. 13.—Map and section of a part of Chocolate Canyon, showing an old débris-filled channel to the east of the present channel. (Section constructed from boring records.)

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The rock exposed along the river is principally effusive, although granite and metamorphosed sediments occur in some places. The effusive rock, consisting of pink and white rhyolite in the form of ash, breccia, and flow, extends from the river level apparently to altitudes of several thousand feet, and is characterized by conspicuous cliffs, erratic forms of erosion, and rock slopes barren of vegetation.

Physiographic changes similar to those at Bulls Head and elsewhere were noted in Chocolate Canyon. At Lighthouse Rock the river has apparently left its old channel and cut laterally into the rhyolite, leaving Lighthouse Rock standing in the water. A boring in the channel at this point failed to reach bed rock at a depth of 80 feet. Farther down the river, near Picacho, several borings in the river bed failed to reach solid rock at a depth of 100 feet.

Probably the best illustration of changes in the course of the river in this vicinity is to be found at the so-called Cacopah dam site of the Reclamation Service, near the southern end of Chocolate Canyon. At this point the Colorado flows close to the rhyolite hills on the west, with one rock island standing in the river and another on the eastern bank. (See fig. 13.) Between these islands and the hills to the east is a broad sand flat.

Borings made at the various places indicated in fig. 13 show that the channel now occupied by the river has been eroded to a depth of about 100 feet, and later filled with sediment, while the old channel to the east is deeper, no solid rock being found at a depth of 138 feet.

A significant observation was made at this point by Homer Hamlin,[a] who noted that in one of the borings the drill penetrated through the rhyolite and entered a gravel bed. (See fig. 13.) The rhyolite is presumably of Tertiary origin, as are also the rhyolites farther north, more fully described elsewhere (p. 83). It is possible that the underlying gravels may be equivalent in age to some of the tilted and consolidated gravels farther north, which were referred by Newberry to the Tertiary, but which the present writer has provisionally correlated with the Temple Bar conglomerate and referred to the Quaternary.

HUALPAI VALLEY.

Location and character.—The Hualpai Valley, about 60 miles long and 25 miles wide, is located in the northeastern part of the region described. Except for a few miles at the northern end, it is an undrained basin, in the lowest part of which flood waters gather and remain until they either evaporate or sink into the valley filling. "Red Lake," thus formed, contains water for periods varying from a few days to several months. At other times it is a broad, barren mud flat.

[a] Personal communication.

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The floor of the Hualpai Valley is nearly level at an altitude of about 3,000 feet and is met on either side by mountain slopes at high angles. The plateau to the east drains away from Hualpai Valley into Colorado River, and the drainage from the White Hills and the Cerbat Mountains to the west and from the Hualpai and Peacock mountains to the south is so small as to be negligible. The only stream worthy of note that enters this great valley is Truxton Creek, the bed of which is usually dry, but which occasionally contains floods of great volume.

Structure.—The Hualpai Valley is a structural trough formed by faulting and block tilting. The Grand Wash fault, with a displacement of 10,000 feet or more at the mouth of Grand Canyon, continues southward into the valley, together with several smaller faults to the west. The general trend of this fault zone in the vicinity of Colorado River, where it is best known, suggests that it may extend through the Hualpai Valley beneath the detrital accumulations and reappear in the fault west of the Hualpai Mountains. On the other hand, extensive displacements by faulting have taken place along the Cottonwood and Aquarius cliffs (see pp. 19–20), and it is possible that these cliffs mark the southward extension of the Grand Wash fault.

At the northern end of the valley the sedimentary formations are tilted steeply to the east; along the eastern flank of the White Hills and Cerbat Mountains the sheets of basalt dip eastward beneath the valley floor. The trough formed by this downthrow to the east has been filled with rock débris to some unknown depth; a well bored 700 feet deep near the head of Hualpai Wash did not pass through it. The material on the alluvial slopes is coarse, but in the center of the valley it is fine and is continually shifted by the winds.

BIG SANDY VALLEY.

Location and character.—The Big Sandy Valley is located between the Aquarius Cliffs on the east and the Hualpai Mountains and Aubrey Hills on the west, and extends from Hackberry southward to Williams River. The lowest part of the valley, known as Big Sandy Wash, lies at the foot of the cliffs as far south as Signal, but at this point the Big Sandy leaves the main valley and passes through Signal Canyon. Several streams of considerable size emerge from the plateau to the east through deep, narrow canyons and discharge into the Big Sandy. The largest of these are White Cliff, Trout, and Sycamore creeks.

That portion of the valley between the Hualpai Mountains and Big Sandy Wash consists of a long, graded detrital slope (see fig. 2, p. 24), more or less deeply cut by parallel washes, such as Deluge Wash. This highly inclined detrital slope, the western fault scarp of the Hualpai Mountains, and the fault scarp to the east (Aquarius Cliffs) all terminate at the south in practically the same latitude. The southern end of the valley, between the Artillery Mountains and

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the Aubrey Hills, has a slight inclination to the east, but is in general an undissected and undrained detrital plain.

Rock formations.—The oldest rocks in the Big Sandy Valley are the granites exposed in the bordering mountains and cliffs, which, because of their resemblance to the granite beneath the Cambrian sediments in the Grand Wash Cliffs, are thought to be of pre-Cambrian age. They are overlain in places by Tertiary andesites.

The trough formed by these older rocks is partly filled with rock débris which has been later exposed by erosion. The oldest detrital beds have been upturned and eroded to depths of 800 feet or more. They are composed of clay, sand, and gravel, and in places contain

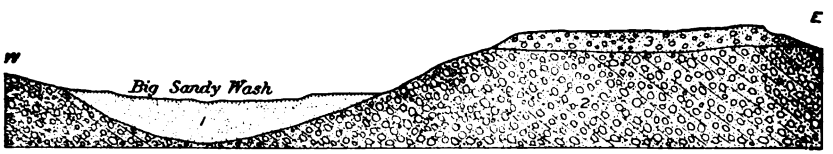

FIG. 14.—Sketch section across Big Sandy Wash near mouth of Deluge Wash, showing the older gravels tilted eastward, eroded, and overlain by younger gravels, and again eroded and partly covered by recent flood-plain deposits. 1, Flood-plain deposits; 2, Temple Bar (?) conglomerate; 3, gravel.

granite bowlders 5 to 8 feet in diameter. In other places, as at Deluge Wash (Pl. IV, *B*), they are composed of clay and fine, well-stratified sand and volcanic ash.

Within the valley eroded in the oldest tilted detrital beds, and resting with horizontal bedding upon their eroded edges, is a second series of gravel deposits. These are perhaps best exposed near the mouth of Deluge Wash, where they are about 50 feet thick. This second gravel accumulation was in turn eroded and a third deposit laid down. (See fig. 14.)

In general character and stratigraphic position the oldest detritus corresponds with the Temple Bar conglomerate, the middle with the

FIG. 15.—Sketch section across Big Sandy Wash at the mouth of Trout Creek, showing the older gravels overlying granite, tilted eastward, and terminating against the granite of Cottonwood Creek. 1, Flood-plain deposits; 2, Temple Bar (?) conglomerate; 4, granite.

Chemehuevis gravel, and the youngest with the flood-plain deposits of the Colorado Valley, but no definite correlation can be made at the present time.

Structure.—The Big Sandy Valley is a trough formed by faulting. The fault zone along the Grand Wash and Cottonwood cliffs continues southward to the Aquarius Mountains. Recent movement along this zone is indicated by the displacement of portions of the andesite sheet at the northern end of the valley and by the faulted and tilted gravel beds near the mouth of Trout Creek (fig. 15), where the strata incline

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32° to the east and end abrubtly against the granite at the fault line. This evidence of faulting, considered in connection with the faulting and block tilting in the Hualpai Mountains, indicates that the Big Sandy Valley was formed by a downthrow of the eastern edge of the Hualpai block. (See fig. 2 and section *S–S'*, Fl. V, p. 24.)

SIGNAL CANYON.

At the town of Signal the Big Sandy leaves the débris-filled trough and passes through a rock gorge known as Signal Canyon. The rocks exposed are coarse-grained granites in the northern part of the canyon and andesites in the southern part. These rocks had been deeply dissected previous to the accumulation of the older detrital beds (just described) which later filled the old valleys and were in turn buried beneath effusive rock. Later, during the erosion of Signal Canyon, these old valleys were reexcavated in part, leaving on the mountain sides conspicuous shelves of lava-covered detritus. (See Pl. III, *A*.)

The broad, débris-filled trough here called the Big Sandy Valley continues southward west of the Artillery Mountains to Williams Canyon, where the detritus is seen to extend lower than the bed of Williams River.

DETRITAL-SACRAMENTO VALLEY.

Location and character.—The Detrital-Sacramento Valley extends from Colorado River on the north to Williams River on the south, between the Cerbat and Hualpai mountains to the east and the Black Mountain Range to the west. Thus defined it is about 130 miles long and 5 to 15 miles wide. The northern part of the valley, drained by Detrital Wash, is locally known as the Detrital Valley, and the central part as the Sacramento Valley. (See Pl. XI.) The southern part bears no name, but since it is the southern continuation of the Sacramento Valley, the whole is here called the Detrital-Sacramento Valley.

The valley was apparently formed mainly by erosion, although its form has been modified by crustal movements; such is notably the case west of Chloride, where sheets of basalt, outpoured within the valley, have been tilted eastward. The andesites and rhyolites on either side, from the southern end of Black Mesa northward to Colorado River, are similar in character and occur at about the same level. They are probably remnants of a single effusive mass through which the Detrital-Sacramento Valley was eroded.

The depth to which this valley was cut is not definitely known. At the northern end it was deeper than the present Colorado Valley (altitude 800 feet), and in Williams Canyon (altitude 505 feet) it extends beneath the bed of the river. The maximum depth between

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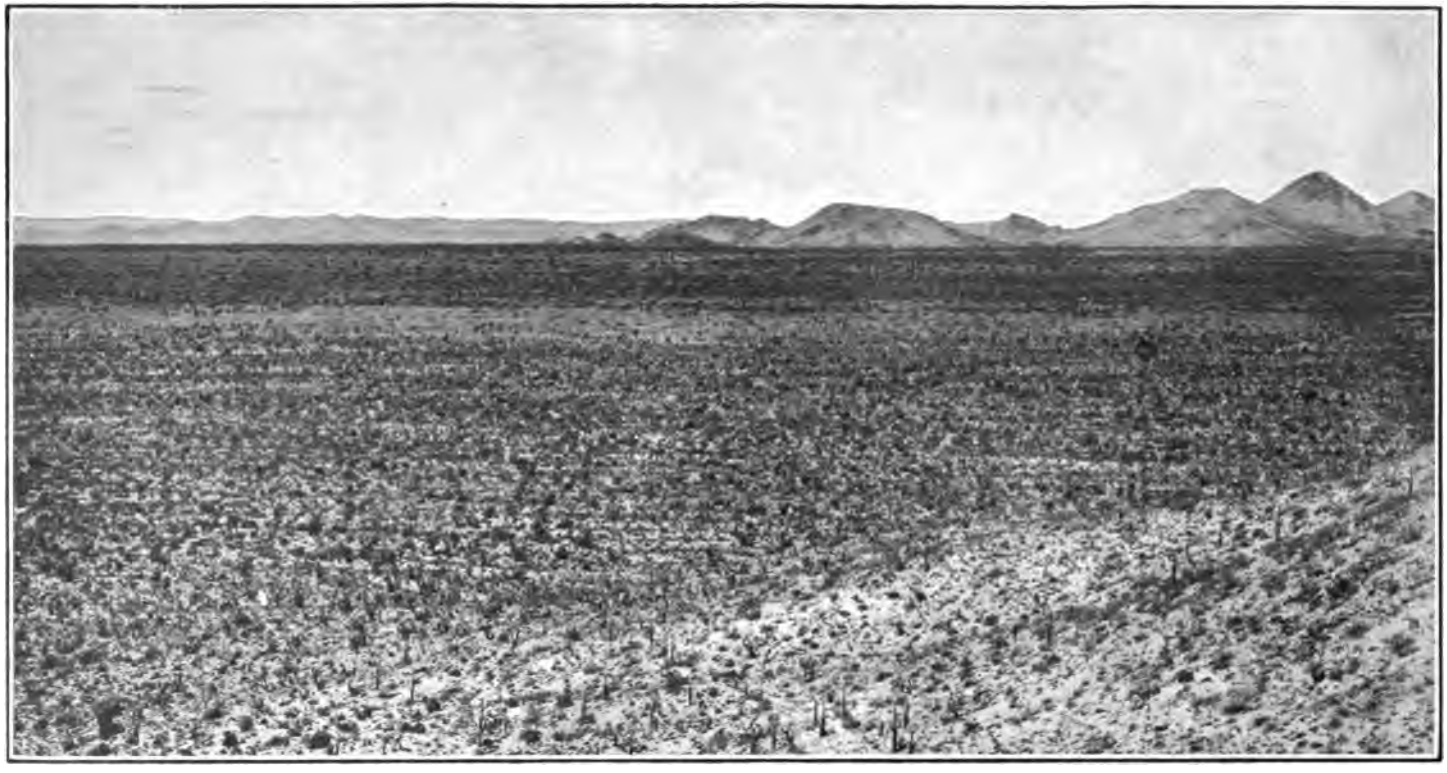

SACRAMENTO VALLEY AT SOUTH END OF HUALPAI MOUNTAINS.

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these extremities is not known. At Yucca (altitude 1,804 feet) the bottom of the gravels was reached in a well at a depth of 905 feet, or at an altitude of about 900 feet above sea level. The general altitude of Black Mesa, a few miles west of Yucca, and of the mesa east of the valley near Kingman, is about 3,500 feet. Assuming that the mesas are remnants of the surface which formerly extended across the Detrital-Sacramento Valley, the known depth of erosion at Yucca is about 2,500 feet. Since the valley is known to be deeper than this at both the northern and southern ends, it is probable that the well at Yucca does not penetrate the filling at the deepest point and that the depth of the old valley is greater than 2,500 feet.

Detrital filling.—The Temple Bar conglomerate filling this ancient valley is exposed at the north in the banks of Colorado River (Pl. II) and at the south in Williams Canyon (Pl. VI, *B*). It is composed of horizontally bedded sand, gravel, and wash, and contains sheets of basalt at several horizons. The composition of the filling at the extremities of the valley is described under "Temple Bar" (p. 35), and under "Williams Valley" (p. 54), and need not be repeated here. Where exposed in the washes throughout the valley and penetrated by wells the material does not differ greatly in character. Horizontally bedded sand and gravel containing sheets of basalt and having the same general appearance as the beds at Temple Bar and in Williams Canyon were observed within the valley up to altitudes of 2,500 feet or more, and sheets of basalt within the detrital beds were penetrated in the well at Drake. For these reasons the detrital filling is correlated with the Temple Bar conglomerate.

Considerable erosion has taken place within the Detrital-Sacramento Valley since the filling was completed. Sacramento Wash is 1,000 feet or more lower than the valley floor farther north. This difference in elevation is probably due in part to surface warping, but is regarded as due mainly to erosion.

In general the sands and gravels of the Detrital-Sacramento Valley are covered with angular rock débris, consisting in part of fragments of basalt, andesite, rhyolite, and granite, working their way over the surface as wash from the hills, and in part of the coarser material originally deposited with the sand and gravel and accumulated by surface concentration during the later degradation as the finer material was washed away by the rains or blown away by the winds.

WILLIAMS VALLEY.

Location and character.—Williams River, formerly known as Bill Williams Fork, is formed by the junction of two streams (Big Sandy Wash and Rio Santa Maria) and extends from this junction westward to Colorado River. The south fork, or Rio Santa Maria, emerges through a narrow canyon from the plateau to the east upon a broad

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detrital plain, into which it has cut a canyon several hundred feet deep. At the point where the river crosses the direct southward continuation of the Big Sandy Valley the canyon has been broadened to a basin several miles wide. About 12 miles east of Planet this basin narrows to a gorge about 8 miles long, known as Williams Canyon. The southern wall continues westward to Colorado River, but the northern wall is broken down west of Planet.

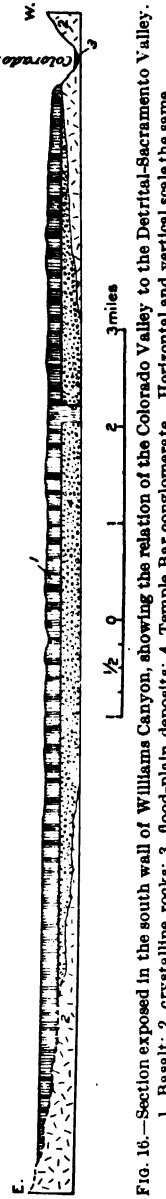

FIG. 16.—Section exposed in the south wall of Williams Canyon, showing the relation of the Colorado Valley to the Detrital-Sacramento Valley. 1, Basalt; 2, crystalline rocks; 3, flood-plain deposits; 4, Temple Bar conglomerate. Horizontal and vertical scale the same.

Although Williams River crosses the Temple Bar conglomerate, filling the Detrital-Sacramento Valley, it has not excavated a broad basin in it, as it has in the gravels filling the Big Sandy Valley, the difference being due to the protection afforded the conglomerate by the sheets of basalt.

Rock formations.—The oldest rock masses exposed in Williams Canyon are gneisses and metamorphosed sediments consisting of quartzites, slates, and limestones associated with beds of iron ore and veins of copper. Within valleys eroded in these rocks occur beds of the Temple Bar conglomerate. In the Detrital-Sacramento Valley, which crosses the Williams Valley, a thickness of nearly 1,000 feet is exposed under a sheet of basalt 800 feet thick. (See fig. 16.) The lowest part of the detritus extends beneath the bed of Williams River, but the underlying gneiss and granite are exposed at the sides of the old valley. The horizontally bedded sand and gravel have been disturbed locally, probably by the eruption of the basalt which burst upward through them.

Geologic section in Williams Canyon, 2 miles east of Colorado River.

	Feet.
Massive flow of basalt	800
Alternating layers of sand and basalt	40
Sand and gravel intersected by basalt dikes	900
Granite gneiss	50

Between the gravels and the massive flow of basalt at the top is a transition zone 40 feet in thickness, containing at the point where the section was made (Pl. VI, *B*) five thin sheets of basalt separated by beds of sand. Each sheet of basalt was outpoured upon what was then the surface, and each in turn was covered by sand. The sand is metamorphosed for a few inches beneath each

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sheet and contains fragments of scoriaceous basalt immediately above each sheet. The basalt extends completely across the old débris-filled valley to the rock walls on either side.

That the basalt burst upward through the sands and gravels in the midst of the old filled valley is proved by the occurrence of a large dike or neck, about 400 feet wide and several thousand feet long, exposed in the Williams Valley near the point where the section was made. The stratified deposits through which this dike broke are disturbed and burned to a brick red for about 300 feet from the dike. Several smaller dikes occur in the vicinity, and some of the eruptive masses to the north, seen only from a distance, appear to be volcanic necks standing as sharp pinnacles several hundred feet above the level of the surrounding plain.

OTHER VALLEYS.

Location and character.—There are several intermontane plains south of Williams River, known as the Cactus, Posas, and Ranegras plains, McMullan Valley, and an extensive unnamed plain south of the Harquahala Mountains. These are parts of the great desert plains of southwestern Arizona. They are, in part at least, old débris-filled valleys similar to those just described, but their original depth and the character of the filling can be judged only by surface indications. These plains have a general altitude of about 2,000 feet in the eastern half of the area described, and decline gradually westward to Colorado River (altitude 345 feet).

Detrital filling.—Near Williams River the Cactus Plains have been somewhat dissected by erosion; detrital bluffs 500 feet or more in height occur, while the total depth of erosion into the detritus (the difference between the general surface altitude of 2,000 feet and the river elevation of 600 feet) is about 1,400 feet. The bluffs thus exposed are composed of clay, sand, gravel, and angular rock fragments, consisting of granites, andesites, etc., with sheets of embedded basalt. Near the mouth of Date Creek a sheet of basalt about 30 feet thick caps the bluffs, but passes into the detrital beds a short distance back from the face of the cliffs. West of Date Creek two basalt sheets occur in the detrital beds. The lava was outpoured upon an old surface and metamorphosed the material beneath it to some extent. At the surface of each of the lava sheets the cavities contain zeolites, and the overlying sands contain fragments of the basalt, indicating that the gravels and the lavas are contemporaneous.

The detrital material exposed in the bluffs is comparable in thickness and has the same general appearance as the oldest detritus in the Big Sandy Valley and the Temple Bar conglomerate of the Detrital-Sacramento Valley. The basalt sheets embedded in it have the same

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petrographic character as those contained in the Temple Bar conglomerate (see p. 17) and were supposedly erupted at about the same time. For these reasons the detrital filling is correlated tentatively with the Temple Bar conglomerate.

GEOLOGIC HISTORY.

INTRODUCTORY STATEMENTS.

It is desirable to consider at this point the geologic history of the region—to review the facts that have been presented and to emphasize their significance. Certain considerations which depend upon the interrelations of features at various localities are also presented without reference to former descriptions. The reader should be reminded again that the observations were made during rapid reconnaissance trips and that large intervening areas were not examined. With the exception of the Paleozoic formations of the Plateau region, none of the sediments of northwestern Arizona are fossiliferous so far as observed, and the younger formations can not be traced continuously from place to place. The history of the region is largely one of destructive processes, and the ordinary means of correlation are wanting. For these reasons, although the sequence of the events is apparently clear, their places in the geologic time scale can not now be definitely fixed. The observed facts show that the late geologic history of the region is separable into epochs comparable with those established in neighboring regions, but in the absence of adequate correlation data the intention is to emphasize the sequence of events, the provisional correlations being offered only as a working basis.

PRE-CAMBRIAN CONDITIONS.

Crystalline rocks.—Throughout northwestern Arizona the oldest rocks are coarsely crystalline granites and gneisses. In the plateau to the east the granites underlie the Cambrian sandstone and are intersected by less coarsely crystalline intrusives.

Sedimentation.—The pre-Cambrian sediments so extensively developed in the Grand Canyon region apparently once extended over western Arizona, and remnants of them remain at the northern end of the region near Virgin Canyon and from Williams River southward in the southern part of the area examined.

Base-leveling.—Previous to the deposition of the Cambrian sediments there was a long period of erosion during which such sediments as may have been deposited in the eastern part of the region were removed by erosion and the underlying granites were base-leveled. The line representing this base-level may be followed in the cliffs from Grand Canyon to the southern end of the Juniper Mountains.

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PALEOZOIC AND MESOZOIC CONDITIONS.

But little can be said of the history of this region during Paleozoic and Mesozoic time. Cambrian sediments, consisting of sandstone and shale (Tonto formation), underlie the plateau, and were probably deposited over a large part of western Arizona. No Ordovician or Silurian formations have been discovered, and the Devonian of Grand Canyon, described by Walcott,[a] was not identified in the area examined. The Carboniferous is represented by the Redwall limestone, which extends from the Mississippian into the Pennsylvanian, as previously shown in the description of rock formations (pp. 15–16). There is a limited exposure of Carboniferous strata younger than the Redwall in Iceberg Canyon, and Mesozoic formations occur east of the rim of the plateau in a manner which suggests the probability that they originally extended westward over the region described. So far as known, however, no remnants of any of these formations remain west of the cliffs.

Little is known regarding the original extent of the older sedimentary formations in western Arizona or of the circumstances attending their removal. Probably some of the erosion occurred during the Cretaceous period, as suggested by Gilbert,[b] but nothing was found to indicate what proportion of it was accomplished in pre-Tertiary and what in early Tertiary time.

TERTIARY EVENTS.

Explanatory statement.—No great amount of sediment was deposited within the area described during Tertiary time. The period was apparently one of uplift, volcanic activity, and extensive erosion, but it is not known whether the uplift began with the Tertiary or before, nor can the Tertiary be confidently separated from the Quaternary. The sequence of events, based upon physiographic evidence, can be stated with some confidence, but the various epochs can not be confidently referred to established subdivisions of time.

Denudation.—The erosion which removed the older sedimentary formations from western Arizona during early Tertiary and pre-Tertiary time was evidently on an extensive scale. Whatever Paleozoic and Mesozoic sediments had been deposited were stripped off and the underlying granites deeply dissected previous to the eruption of the oldest effusives. The Eocene sediments extensively developed farther north in parts of the plateau region are apparently absent from western Arizona, and the extensive denudation may have been accomplished in large part during Eocene time.

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[a] Walcott, C. D., Am. Jour. Sci., 3d ser., vol. 20, 1880, pp. 221–225.
[b] Gilbert, G. K., U. S. Geog. Surv. W. 100th Mer., vol. 3, 1875, pt. 1, p. 134.

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Eruption of andesite.—The oldest effusive rock thus far found in western Arizona is the andesite in the vicinity of Gold Roads, a mining camp on Black Mesa, west of Kingman. The andesite rests upon granite and underlies an extensive series of rhyolites and younger andesites, but no further evidence of its age was obtained. It may be a time equivalent of the great masses of andesite comprising the Pine Valley Mountains and resting upon the Eocene sediments in the southwestern part of Utah. These masses, according to Huntington and Goldthwaite,[a] were probably extruded at the close of the Eocene. The provisional reference of the Arizona andesite to the close of the Eocene is based on the fact that, in the general sequence of events here described, its extrusion occurred between the period of early Tertiary erosion and the long period of base-leveling, during which part of the Mohave peneplain was formed. (See p. 59.)

Crustal movements and erosion.—Either during or shortly after the extrusion of the older andesites further uplift apparently occurred in western Arizona, followed by renewed erosion, which carried away much of the andesite and again exposed the granite. The Paleozoic sediments that formerly extended much farther to the west were eroded away at about the same time and the region reduced to a peneplain, parts of which are still preserved in the Truxton Plateau and in the plateau lying south of Iceberg Canyon, in which soft and hard layers alike are truncated. This may prove to be a part of the Mohave peneplain in southwestern Utah, which in the opinion of Huntington and Goldthwaite[b] was formed after the period of folding of the early Miocene.[c]

Certain phenomena described by Spurr,[d] from Meadow Valley Canyon, a tributary of Virgin River in southern Nevada, strengthen this supposition. He describes a succession of rocks very similar to those found in northwestern Arizona. Extensive beds of rhyolite rest on an eroded surface of older rocks and are overlain by extensive deposits of conglomerate and soft sandstone which he refers with a query to the Pliocene, and these in turn are overlain by basalt and Pleistocene gravel. His description of the Pliocene (?) conglomerate and its position in the sections given indicate that it is probably equivalent to the Temple Bar conglomerate, which is here regarded as Pleistocene. Fig. 16 of Spurr's paper shows faulted Paleozoic sediments peneplaned and overlain by the conglomerate. This faulting may prove to be part of the early faulting of the Plateau region, and the peneplain beneath the conglomerate to be part of the Mohave peneplain, in which case the relations in Meadow Valley Wash would

[a] Huntington, Ellsworth, and Goldthwaite, J. W., The Hurricane fault in the Toquerville district, Utah: Bull. Mus. Comp. Zoöl. Harvard Coll., vol. 42, 1904, p. 217.

[b] Idem, p. 226.

[c] Idem, p. 222.

[d] Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California: Bull. U. S. Geol. Survey No. 208, 1903, pp. 139–148.

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correspond with those found in the Plateau region and would form another link in the chain of evidence that the pre-Quaternary course of Colorado River was through southern Nevada, to the north of the present canyon.

Eruption of rhyolite and younger andesite.—After the formation of the peneplain, extensive masses of rhyolite and andesite, in the form of tuff, breccia, and flow, were spread over its surface, filling the depressions and covering all but the higher parts of the land surface. Although largely removed by later erosion, these lavas still cover wide areas, such as Black Mesa, a large part of the Truxton Plateau, and the mesa in the vicinity of Kingman. These lavas occur also to the east beyond the area described, and far to the south, where they form Castle Dome and the Chocolate Mountains in southwestern Arizona.

In places where the rhyolites and younger andesites occur in more or less regular horizontal beds, as near Kingman and in Black Mesa, they have a maximum thickness of about 3,000 feet. In more mountainous regions, as at the southern end of the Aquarius Mountains, they are apparently thicker. In other places, notably in the Truxton Plateau, they thin and disappear. The thickness of the rhyolites and younger andesites, and their areal distribution, indicate that they originally covered a large part of northwestern Arizona.

The time at which these great masses of igneous rock were extruded is not definitely known. It was after the Mohave peneplain had been formed, at least in large part, for the lavas rest upon the eroded surface. Furthermore, the amount of erosion which followed the extrusion of these lavas places this event far back in the Tertiary. For these reasons, and because of the evidence that the close of the Miocene was a time of mountain forming and of great volcanic disturbance in the Great Basin and the mountains west of it, the extrusions of rhyolites and younger andesites may be provisionally referred to the close of the Miocene.

Formation of the Grand Wash Trough.—Sometime during the middle Tertiary, and apparently before the completion of the Mohave peneplain, the Grand Wash fault was formed, with a displacement of several thousand feet, giving rise to the Grand Wash Trough. This faulting probably corresponds to the early displacements of the Hurricane and other faults described by Huntington and Goldthwaite,[a] and should not be confused with the faulting which accompanied the later uplift of the plateau.

Deposition of the Greggs breccia.—At the north end of the region described local deposition followed the extrusion of the rhyolites and younger andesites. These sediments in the vicinity of Temple Bar lie unconformably beneath the Temple Bar conglomerate and consist

[a] Huntington, Ellsworth, and Goldthwaite, J. W., op. cit., p. 226.

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mainly of angular fragments of rhyolite, but otherwise are similar in character and stratigraphic position to the Greggs breccia, which, as already stated, consists mainly of granitic débris. Both breccias antedate the present course of Colorado River, which has eroded into them. This correlation would tend to place the Greggs breccia in the Pliocene. On the other hand, the physiographic evidence does not seem to favor this correlation. The rhyolites, supposed to have been erupted at the close of the Miocene, rest upon the peneplain, a fact which tends to place the breccia in the Miocene. It is evident, therefore, that the determination of the age of the Greggs breccia must await further investigation.

Erosion of the Detrital-Sacramento Valley.—A long period of erosion apparently followed the rhyolitic eruptions and succeeding accumulation of breccia, during which the Detrital-Sacramento Valley was excavated. Measured from the original surface now represented by the mesas on either side, this valley is 5 to 15 miles wide and 3,000 feet deep, including the gravel filling. It extends from southern Nevada southward to Williams River, where it is apparently interrupted by a lava-covered plateau, but its real continuity is shown by the gravel-filling beneath the lava (fig. 16, p. 54). From the plateau southward it is occupied by Colorado River for a distance of 75 miles, in the basin known as the Great Colorado Valley. Owing to circumstances beyond the writer's control, the old valley was not traced south of this basin. It may be pointed out, however, that at the southern end of the basin the river turns abruptly to the east and passes in a narrow rock canyon through the Chocolate Mountains. The general trend of the old valley suggests that it may continue through the hills west of Chocolate Canyon, or perhaps beneath the lavas, and connect with the Gulf of California (including at that time the Salton Sink), which lies southwest of the Chocolate Mountains.

The origin of the Detrital-Sacramento Valley, although a matter of great interest, can not be fully described until more information is available. It is in a region of profound faulting and surface warping, and may have originated as a succession of depressed areas. But whatever its origin it is believed to have been occupied and greatly modified, if not wholly formed, by a stream of considerable size. The reasons for this belief are as follows:

The beds of volcanic tuff, breccia, and flow in the mesas on either side are composed of the same kinds of rock and are so disposed as to indicate that they may originally have been connected across the intervening space. The width of the valley, 5 to 30 miles, as compared with its length, about 375 miles (including the Great Colorado Valley), together with its somewhat sinuous course, accords more nearly with the conception of a moderately mature river valley than with a succession of downthrown areas. But perhaps the strongest

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argument in favor of its formation mainly by river erosion is the presence, throughout its length, of sands and gravels similar to those known to have been deposited by aggrading streams.

Relation of Colorado River to the Detrital-Sacramento Valley.—The influence of Colorado River has not been considered thus far for the reason that no clear evidence has been obtained of its presence within the area described. The erosion previously accomplished may have been the work of the Colorado, or may have been accomplished by streams now extinct. But with the erosion of the Detrital-Sacramento Valley the recorded history of the Colorado in western Arizona apparently begins. The river changed its course within the area described during Quaternary time, and there are indications that still greater changes occurred in late Tertiary time; but in order to determine the nature and extent of the changes, it would be necessary to examine a large part of the Plateau region, where, on account of recent faulting, uplift, and subsequent erosion, the investigation would be difficult. There was apparently no great difference in elevation between the Basin region and the southern part of the Plateau region during mid-Tertiary time, the Mohave peneplain extending continuously over both. The evidence of peneplanation in the Meadow Valley and in the Toquerville region, and the general trend of the broad valley of the Virgin heading into this region, suggest that the Colorado may have flowed across what is now the Plateau region to the north of its present course and through the valley now occupied by the lower part of the Virgin into western Arizona, where it excavated the Detrital-Sacramento Valley. A large part of Tertiary time must have been consumed in eroding this great valley. If the formation of the peneplain be correctly assigned to the Miocene, and the extrusion of the rhyolites and younger andesites to the close of this epoch, the erosion of the Detrital-Sacramento Valley must have been accomplished in the Pliocene.

Uplift of the plateau.—The Plateau region seems to have been not notably higher than the area west of it until the end of the epoch during which the Detrital-Sacramento Valley was excavated. But at this time it was greatly elevated and faulted. Extensive displacements occurred along its western border, forming the Grand Wash, Cottonwood, and Aquarius cliffs. Probably the tilting of the great crust blocks like that of the Hualpai Mountains occurred about the same time. The block at Iceberg Canyon, previously upturned, was again tilted, together with the overlying Greggs breccia. The Cerbat Mountains were probably uplifted to some extent, but the principal movement there seems to have been downward, forming Hualpai Valley. About the same time flows of basalt occurred in the Detrital-Sacramento Valley west of Chloride, in the Cerbat Mountains, and elsewhere, which may antedate the

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crustal movements or may have occurred as accompaniments of the initial movements and later have been tilted to their present position.

Effect of uplift on Colorado River.—The lines of faulting and the axes of uplift were developed across Colorado River and no doubt materially changed its course. Whatever this may have been previously, the uplift of the plateau finally established its direction by causing it to erode the Grand Canyon. In the low-lying region west of the plateau the river flowed across the Grand Wash Trough, previously filled with the Greggs breccia, across the truncated edges of the upturned sediments now exposed in Iceberg Canyon, across a second débris-filled trough near Hualpai Wash, through the crystalline rocks of the Virgin Mountains, and into the previously formed Detrital-Sacramento Valley, which it apparently followed thence to the sea.

The reasons previously given in the detailed descriptions for believing this to be the river's former course may be briefly summarized as follows: Boulder and Black canyons west of the Detrital-Sacramento Valley are apparently younger than Virgin and Iceberg canyons. Remnants of the Temple Bar conglomerate, which occurs typically as the filling of the Detrital-Sacramento Valley, are found in Virgin and Iceberg canyons in positions that indicate deposition after these canyons were eroded; no such occurrence was observed in the canyons west of the Detrital-Sacramento Valley. There are gravel formations similar to the Temple Bar conglomerate west of the Black Mountain range, but they were apparently deposited previous to the erosion of Boulder and Black canyons.

QUATERNARY (?) EVENTS.

First canyon cutting.—During the first epoch of erosion that followed the uplift of the plateau Colorado River eroded Grand Canyon to a depth of 5,000 feet or more beneath the Mohave peneplain. West of the plateau it cut to a depth of somewhat more than 1,400 feet beneath this plain in Iceberg and Virgin canyons. The erosion in the Detrital-Sacramento Valley was probably correspondingly great, but little is known of this on account of the detrital filling of the valley which has not been removed.

The reasons for departing from the usage of former writers who assign the erosion of Grand Canyon to late Tertiary time are twofold: First, the Temple Bar conglomerate, deposited immediately after the first epoch of canyon cutting, is regarded as a Quaternary deposit for reasons stated in the section next following; second, the crustal disturbances resulting in the elevation of the plateau and the erosion of the Grand Canyon were of such magnitude and far-reaching influence in effecting radical changes in the geography and geology of the region that, considering this region alone, without reference to established subdivisions, they appropriately constitute the separation

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between two great periods of time. Since, therefore, the canyon cutting followed the uplift, it falls into the later or Quaternary period.

Deposition of the Temple Bar conglomerate.—After the canyon had been eroded to something like its present depth some change occurred which caused the river to deposit sand and gravel from Grand Canyon to the Gulf of California. Between the mouth of the canyon and the Detrital-Sacramento Valley no great volume of the gravels accumulated, owing to the limited dimensions of that part of the valley; but in the broad Detrital-Sacramento Valley extensive deposits were laid down to a depth of something like 2,000 feet.

Similar deposits were formed in other valleys of the Southwest, and the low-lying interstream areas were built up with angular rock débris derived from the near-by mountains. As previously described, the detrital formations of various parts of the Territory can not be definitely correlated, but beds apparently equivalent to the Temple Bar conglomerate are found throughout the Southwest.

During this epoch of deposition numerous volcanic eruptions occurred. Sheets of basalt underlie the gravels in some places and in others are included within them at several horizons. Toward the close of the epoch eruptions occurred near the mouth of Williams River, the molten basalt bursting upward through the filling of the Detrital-Sacramento Valley and spreading over its surface to a depth of 800 feet or more, apparently forming a volcanic dam. This sheet has since been greatly eroded and its original extent has not been determined. Lava hills north of Williams River having the appearance of volcanic necks suggest that the center of eruption and the real obstruction across the valley may have been between the Mohave Mountains and the Aubrey Hills, the sheet of compact lava south of Williams River being an outflow from this center.

A dam 800 feet high thrown across Colorado River at this place would have created slack-water conditions not only throughout the entire length of the Detrital-Sacramento Valley, but far into Grand Canyon, and must have facilitated the deposition of sand and gravel, which had previously accumulated in the valley to a depth of about 1,000 feet. The altitude of the basalt sheet does not differ greatly from that of the aggraded floor of the Detrital-Sacramento Valley to the north, and of the sand and gravel remnants found far above the river in the walls of Virgin Canyon. Deposition of sand and gravel apparently continued long after the extrusion of these lavas, filling the Detrital-Sacramento Valley to a level corresponding to the surface of the lava sheet, an additional depth of about 800 feet.

It is probable that the volcanic dam did not at once divert the river from its former course through the Detrital-Sacramento Valley, for the upper part of the valley filling, so far as observed, does not

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differ in physical character from the lower 1,000 feet, which is presumably a river deposit. The coarseness of the sediment and the absence of terraces along the margin are unfavorable to the supposition that the valley was transformed into a lake separated from the river. It is more probable that the water of the river continued to flow through the temporary lake, filling it rapidly with sediment or even building above the level of the dam before being finally deflected from its former course. A general view of the aggraded valley floor and its relation to the neighboring hills is shown in Pl. XI.

While accumulation was going on in the Detrital-Sacramento Valley other valleys and basins were filling with sediment. The Big Sandy, probably flowing at that time west of the Artillery Mountains and through the Cactus Plains to the Colorado, was evidently building up its course, and the Hualpai Valley, probably at first a lake basin, was filling with sediment. Briefly stated, it is probable that the Temple Bar conglomerate is a part of the widespread accumulation which occupies the low places of the Southwest from central New Mexico to California and northward over the entire basin region. The probability that sedimentation over a wide area was due to a single far-reaching cause or group of causes constitutes one of the principal reasons for correlating the Temple Bar conglomerate with the Lake Bonneville beds and less confidently with the Gila conglomerate. It is not the author's intention to argue that these beds are exact equivalents. They apparently belong, however, to a single division of time, like the Pleistocene epoch of the Quaternary.

It may not be out of place, furthermore, to reiterate the statement that the reconnaissance surveys were inadequate for the final solution of the broad problems which, on account of their local bearing, must of necessity be discussed. The age of the Temple Bar conglomerate and its relation to other similar deposits, the changes in the course and activities of Colorado River, and the causes of these changes, are all problems to be finally solved only after much more extended investigation.

River diversion.—The extensive aggradation caused some of the streams to abandon their old courses, and the sand and gravel filling the valleys were in some cases covered with angular wash. A notable occurrence of the diversion of a river and the burial of its gravels, in the Salt River Valley, has been described by the writer,[a] who shows that Salt River, which now flows north of the Salt River Mountains, formerly joined the Gila east of these mountains, about 40 miles farther upstream.

Colorado River left the Detrital-Sacramento Valley and established a new course west of the Black Mountain Range, from Boulder Canyon

[a] Lee, W. T., Underground waters of Salt River Valley, Arizona: Water-Supply Paper U. S. Geol. Survey No. 136, 1905, pp. 125–127.

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to the mouth of Williams River, a distance of about 125 miles. This diversion may have been due in part to the volcanic dam which had been thrown across the Detrital-Sacramento Valley near Williams River; or it may have been caused wholly by the normal deflection of the river over the aggrading surface—an action well illustrated in the frequent changes of course over the flood plains and delta of the Colorado at the present time. It is noteworthy in this connection that the volcanic dam near Williams Canyon, the highest remnants of the detrital beds, and the mountain ridges through which the river cut at Boulder and Black canyons, do not differ greatly in altitude.

Second canyon cutting.—A second epoch of canyon cutting was brought about by some change which caused the streams throughout the Southwest to erode their channels. The streams which had not been deflected from their former courses reexcavated their old valleys; those that had been deflected cut new canyons. Colorado River reexcavated its old valley from Grand Canyon westward to the Detrital-Sacramento Valley, where it left its former course, passing westward across the Black Mountain Range and thence southward to the mouth of Williams River, where it returned to the old valley which it now occupies.

Viewed from the standpoint of existing topography, a more difficult course could scarcely have been selected. Instead of reexcavating the Detrital-Sacramento Valley, where the only hard rock to be eroded was the volcanic dam, it eroded four rock canyons (Boulder, Black, Mohave, and Aubrey) and crossed four débris-filled basins (Las Vegas, Cottonwood, Mohave, and Chemehuevis) before returning to its former course. The excavation of the detritus in the basins was naturally more rapid than the work in the hard rock of the ridges separating them, and the result is the conspicuous alternation of short, sharp canyons and basin-like valleys characteristic of lower Colorado River.

During this epoch the downcutting was apparently very rapid, the rock canyons being narrow, their walls rising abruptly from the water's edge, as in Black Canyon (Pl. VIII, *B*) and in Boulder Canyon. The rapidity of the downcutting is perhaps most strikingly shown where the river has cut through the Temple Bar conglomerate, as at Temple Bar, leaving the poorly consolidated gravels standing in perpendicular cliffs hundreds of feet high. (See Pls. II and VIII, *A*.) The occurrence of these high cliffs of unconsolidated gravel and the absence of extensive weathering are not wholly in accord with the suggestion that the change from the aggrading to the degrading condition of the river was due entirely to a change of climate.

Deposition of Chemehuevis gravel.—Some influence not certainly known brought the second epoch of erosion to a close and caused Colorado River and other streams of the Southwest again to fill their

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valleys with sand and gravel. The open basins which had been excavated along the Colorado while the canyons were being cut in the harder rock were filled to a depth of several hundred feet with material which has been called the Chemehuevis gravel, and which extends from the mouth of Grand Canyon to the Gulf of California. In the midst of this epoch some change occurred which caused the accumulation of coarser material in the vicinity of Bull Head. This change, however, may have been local, as the division into lower and upper gravels is not conspicuous in other places, so far as observed.

During the accumulation of the Chemehuevis gravel Colorado River evidently shifted its course within narrow limits over the aggrading valley floor, as it had done over a much wider area during the accumulation of the Temple Bar conglomerate.

Third canyon cutting.—When the river again began to erode its channel it reexcavated for the most part the old valley, but in a number of places abandoned its former course and cut rock gorges, leaving the gravel-filled channel at one side, as in Cottonwood Valley (p. 37), Pyramid Canyon (p. 38), Mohave Canyon (p. 42), and Chocolate Canyon (p. 48).

For a third time the river eroded to some unknown depth below its present bed. Borings to a maximum depth of about 200 feet at the dam sites of the Reclamation Service failed to penetrate through the gravels.

Formation of flood plains.—In very recent geologic time Colorado River changed again from a degrading to an aggrading stream, and is once more building up its course. In the broad parts of the valley the accumulation is evidenced by the wide bottom lands over which the river frequently changes its course, sometimes gradually by lateral cutting and filling, and sometimes suddenly by cutting a new channel during a flood, forming numerous sloughs, lagoons, and oxbow lakes.

The great depth of the débris-filled channels within the newest canyons, as shown by the soundings for bed rock, raises the question, What proportion of the depth should be attributed to the normal cutting of the river and what proportion to permanent filling?

Cooley[a] shows that Missouri River at Nebraska City probably erodes its bed to a depth of 70 to 90 feet. Near Omaha the depth of scour and fill during the year 1883 amounted to about 40 feet. On this subject Chamberlin[b] remarks: "In the drift-filled bottoms of the great branches of the Mississippi system it is wholly within bounds to regard at least the upper 40 or 50 feet of the deposit over which the

[a] Report Chief Eng. U. S. A. for 1879–80, pt. 2, pp. 1060–1071. See also Chamberlin and Salisbury, Text Book of Geology, vol. 1, p. 185.

[b] Chamberlin, T. C., Jour. Geol., vol. 11, 1903, p. 72.

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river meanders as subject to scour and fill, and to entertain the suggestion that the deeper portions down to 100 feet or more may be similarly affected."

Some instructive data were secured during the construction of bridges across Mississippi and Missouri rivers. N. M. Fenneman[a] has made a special study of this subject and states that the depth of scour, as shown by the occurrence of buried wreckage and also by direct soundings, is 100 feet or more, and that the occurrence of gravels resting on freshly polished rock at a maximum depth of about 335 feet is interpreted as showing that the river transports gravels of considerable size and actively erodes its bed to this great depth. It seems possible, however, that some part of this material may be due to permanent filling in a glacial or preglacial valley, such as are known to exist in the Mississippi Valley.

It is probable that the depth to bed rock shown by the soundings at the various dam sites is largely due to the normal action of the river, cutting deep in times of flood and filling the channel at times of low water. It is equally probable, however, that the channel is to some extent permanently filled.

RÉSUMÉ OF HISTORY.

For convenience of reference, the succession of epochs and their possible time relations are tabulated below.

Table of events in geologic history in western Arizona.

Period.	Epoch.	Deposition epoch.	Erosion epoch.
Quaternary.	Recent	11. Formation of flood plains; accumulation still in progress.	
		10	Rejuvenation of streams; Colorado reexcavates old valley in part and cuts several short rock gorges.
		9. Deposition of the Chemehuevis gravel.	
		8	Rejuvenation of streams; Colorado River, flowing west of the Black Mountains, lowers its bed 2,000 feet or more and cuts Aubrey, Mohave, Black, and Boulder canyons.
	Pleistocene	7. Widespread aggradation and volcanic eruption. About 2,000 feet of the Temple Bar conglomerate deposited.	
		6	Uplift of the Colorado Plateau; erosion of Grand Canyon; flow of Colorado River in the Detrital-Sacramento Valley.
?	?	?	?
Tertiary.	Pliocene	5	Erosion of the Detrital-Sacramento and other valleys.
	Miocene	4. Local deposition; eruption of rhyolite and andesite.	
		3	Peneplanation and recession of the Yampai Cliffs.
	Eocene	2. Eruption of andesite.	
		1	General degradation.

[a] Personal communication.

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CORRELATIONS.

Explanatory statements.—Although no definite correlations can be made between the products of deposition and erosion of this and other regions, there are certain presumptions worthy of consideration. The succession of Quaternary events in western Arizona is similar to that of the Lake Bonneville and other inland regions, and the long epochs of erosion and thick deposits of sediment represent comparable lengths of time for each region. Western Arizona is a part of the great area of western America which underwent extensive changes of elevation during Tertiary and Quaternary time, the various epochs of which were recorded in marine deposition and erosion along the Pacific coast. Since western Arizona is a part of the Pacific drainage area, although far inland, it is presumably true that the great epochs of the coast correspond in some measure with the great epochs of the interior, inasmuch as the thick marine deposits must represent long periods of erosion of the land areas.

Comparison with Lake Bonneville history.—In his summary of the history of the Lake Bonneville oscillations Gilbert [a] enumerates the following events, given in order from oldest to youngest:

1. Erosion. Gilbert says: "This we may call the pre-Bonneville low-water epoch. It was of great duration compared with those enumerated below."

2. Deposition. First Bonneville epoch of high water; deposits of Yellow Clay. This epoch is estimated (p. 316) as being five times as long as the second epoch of deposition (4).

3. Erosion. Represented by unconformity and by alluvial deposits. The duration is estimated (p. 316) as greater than that of the final retreat of the water (5).

4. Deposition. Second Bonneville epoch of high water; deposit of White Marl.

5. Final retreat of water, intermittently, to present stage.

The thickness of the Lake Bonneville beds was not known at the time of Gilbert's writings, nor is their maximum thickness yet determined. Boutwell [b] has shown that a 2,000-foot well at the eastern margin of Salt Lake, near Farmington (altitude 4,231 feet), does not penetrate through the fragmental beds. A similar thickness of sediments has recently been found in a deep boring at Neels, Utah (altitude 4,621 feet), a station on the San Pedro, Los Angeles and Salt Lake Railroad east of Sevier Lake. The well, which was completed in 1906, is 1,998 feet deep and penetrates 1,944 feet of sedimentary matter before reaching bed rock, which is granite.

[a] Gilbert, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890, p. 259.

[b] Boutwell, J. M., Oil and asphalt prospects in Salt Lake basin: Bull. U. S. Geol. Survey No. 260, 1904, p. 471.

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A driller's record, which was apparently kept with exceptional care, exhibits no change in character to indicate that the lower part of the beds are pre-Bonneville in age. It is worthy of note that Neels is located in the narrow neck of Lake Bonneville that connected Escalante Bay with the larger body of water to the north, as shown in Gilbert's map (Pl. III of the Lake Bonneville monograph). It is probable that the broader parts of the lake were much deeper than this narrow strait, and that the sediments filling them were correspondingly thicker.

Because of the importance of this well in showing the character and depth of the Lake Bonneville sediments, the driller's record is here given:

Record of San Pedro, Los Angeles and Salt Lake Railroad well at Neels, Utah.

	Thickness (feet).	Depth (feet).
Surface soil	4	4
Sedimentary (alkali)	5	9
Fire clay	40	49
Water-bearing quicksand	9	58
Shale and soapstone	21	79
Rock (sedimentary)	6	85
Water-bearing quicksand	3	88
Soapstone	11	99
Soapstone with fossil bowlders	39	138
Water-bearing quicksand	4	142
Fire clay	12	154
Blue waxy clay	34	188
Gray shale and clay mixed	7	195
Gray waxy clay	36	231
Lava rock	12	243
Blue waxy clay	12	255
Sedimentary sandstone	6	261
Blue waxy clay	25	286
Water-bearing quicksand	6	292
Blue waxy clay	28	320
Water-bearing quicksand	7	327
Sedimentary sandstone	10	337
Yellow clay	16	353
Water-bearing quicksand	5	358
Yellow clay	27	385
Blue waxy clay	110	495
Yellow clay	15	510
Sedimentary sandstone	24	534
Blue waxy clay	17	551
Soapstone	50	601
Blue waxy clay	11	612
Silt	8	620
Water-bearing quicksand	3	623
Yellow clay	53	676
Sedimentary sandstone	12	688

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	Thickness (feet).	Depth (feet).
Yellow clay	34	722
Blue waxy clay	117	839
Yellow clay	9	848
Blue waxy clay	210	1,058
Blue shale (sand mixed)	18	1,076
Blue waxy clay	13	1,089
Blue shale	45	1,134
Blue shale (sand mixed), yielded hot water	71	1,205
Red shale	12	1,217
Blue shale	70	1,287
Red shale	24	1,311
Blue shale	28	1,339
Red "keel" stone	6	1,345
Water, sand, gravel, and bowlders	70	1,415
Sedimentary sandstone (brown)	35	1,450
Red sandstone	95	1,545
Red shale (burned)	35	1,580
Trap rock (dark brown)	36	1,616
Red shale (burned)	56	1,672
Lava rock with calcite crystals	14	1,686
Red sandstone	68	1,754
Red clay (sticky)	48	1,802
Volcanic deposit, ash, and bowlders	105	1,907
(Gas under pressure sufficient to raise 6,200 pounds of tools 400 feet.)		
Bowlders (cemented)	6	1,913
Cavity	9	1,922
Bowlders	22	1,944
Cavity	6	1,950
Granite with cavities and gas	48	1,998
	1,998	

At the risk of carrying comparisons too far, attention is called to the possible correspondence between the Quaternary epochs of western Arizona and those of the Lake Bonneville basin. The high stages of Lake Bonneville have been explained as being due to the changes of climate toward increasing precipitation, and the low-water stages toward increasing aridity. Periods of great precipitation (and high water in an undrained lake) are those of active stream erosion, and, other things being equal, the periods of sedimentation in Lake Bonneville should be the periods of stream erosion in neighboring regions. On this assumption Gilbert's first Bonneville epoch of high water, during which 2,000 feet or more of sediment consisting largely of fine material was deposited, seems to correspond in duration and position in the time scale to the erosion of Grand Canyon (epoch 6 of the Arizona scale); his first epoch of low water, to the deposition of the Temple Bar conglomerate; his second Bonneville epoch of high water, to the erosion of Black and Boulder canyons (epoch 8 of Arizona); and his final epoch of desiccation, which was

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accomplished intermittently, to the deposition of the Chemehuevis gravel and the following minor epochs represented along lower Colorado River. Whether so close a parallelism of events is warrantable or not, it is evident that the general sequence of events as recorded in the Bonneville basin is similar to that of the Colorado Valley.

Comparison with southern California.—Hershey[a] has arrived at a conclusion regarding the length of Quaternary time and the complexity of its history which is similar in a general way to that shown by the epochs of the Bonneville basin and of western Arizona. Probably the most significant feature of his subdivisions in relation to the phenomena of western Arizona is a long epoch of erosion at the beginning of the Quaternary, which in his opinion is much longer than all the subsequent epochs combined. This epoch may, on further study, prove to be equivalent in point of time to the erosion of Grand Canyon.

Comparison with the Pacific coast.—In studies of the marine beds of the Pacific coast, Arnold[b] shows that, while the epochs of the Tertiary and Quaternary are very fully represented, the subdivisions do not conform in all cases to those of the standard time scale. The division of Tertiary time as given in his publications, which in personal interviews he asserts will hold good for the Pacific coast generally, is shown in the following table:

Correlation table of the marine Tertiary and Pleistocene formations of the Pacific coast.

Period.	Epoch.	Formation.[c]
Quaternary	Pleistocene	San Pedro, 1,000 ± feet.
Tertiary	Pliocene	Merced, 5,000 ± feet.
		Purisima, 800 ± feet.
	Transitional	
	Miocene	San Pablo, 1,500 to 2,000 feet.
		Monterey, 2,500 ± feet.
		Vaqueros, 3,000 ± feet.
	Oligocene	San Lorenzo, 2,300 ± feet.
	Eocene	Tejon, 4,000 ± feet.
		Martinez, 1,000 to 2,000 feet.

[a] Hershey, O. H., The Quaternary of southern California: Bull. Univ. California Dept. Geol., vol. 3, 1902, pp. 1–30.

[b] Arnold, Ralph, The Tertiary and Quaternary pectens of California: Prof. Paper U. S. Geol. Survey No. 47, 1906, p. 9.

[c] In this column full lines represent unconformity; broken lines, conformity.

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According to Arnold, the great time breaks occurred: (a) At the close of the Eocene, the break in this case being indicated by a distinct change of fauna; (b) before the close of the Miocene; and (c) sometime during the Quaternary, the latter two being erosion breaks. It seems probable that the long periods of sedimentation along the Pacific coast may be equivalent in a general way to the periods of quiet erosion described in western Arizona, and that the great and widely recognizable unconformities of the coast may correspond to the periods of crustal disturbances and volcanic activity of the interior. Thus the long period of erosion resulting in the formation of the Mohave peneplain may correspond to the deposition of the Vaqueros and Monterey formations, and the eruptions of rhyolite in Arizona to the unconformity between the San Pablo and the Monterey, which is associated with the volcanic eruptions of the coast region.

The similarity in succession of Quaternary events in the two regions is not striking. Pleistocene time is represented on the coast by thick sediments and Recent time by some of the raised sea beeches. The thickness of the Pleistocene sediments renders it probable that the time required for their deposition is comparable with the long period of erosion during early Quaternary in the Arizona region, and the relative position of these epochs in the time scale apparently warrants provisional correlation. The terraces of the coast may correspond in time with the various epochs of erosion and deposition of the Arizona region.

Comparison with the Plateau region.—In the Plateau region the subdivision of Tertiary and Quaternary time is based mainly on physiographic evidence. Davis[a] has shown that there were two main cycles of erosion, designated the plateau cycle and the canyon cycle. During the first or plateau cycle a large area in northern Arizona and southern Utah was reduced to a peneplain. The original surface of this peneplain is preserved in places by lava flows, as on the Shiwitz Plateau in northern Arizona and near Toquerville, Utah,[b] but has generally been dissected by later erosion. The peneplain will perhaps be best recognized—if due allowance be made for subsequent erosion—as the surface of the plateau in which Grand Canyon is eroded in northern Arizona. During the second or canyon cycle Grand Canyon was carved by the Colorado, and the peneplain, now elevated, was dissected to a less extent by the smaller streams.

Following Davis, Huntington and Goldthwaite in their description of the Toquerville region of southwestern Utah emphasize the importance of these cycles and add many details which aid in studying

[a] Davis, W. M., An excursion to the Grand Canyon of the Colorado: Bull. Mus. Comp. Zoöl. Harvard Coll., vol. 38, 1901, pp. 107–201.

[b] Huntington, Ellsworth, and Goldthwaite, J. W., The Hurricane fault in the Toquerville district, Utah: Bull. Mus. Comp. Zoöl. Harvard Coll., vol. 42, 1904, p. 231.

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the geologic history of the Grand Canyon region. The succession of Tertiary and Quaternary events described by them may be summarized, in order from oldest to youngest, as follows:

1. Eocene. A period of deposition during which the Plateau region was low.
2. A period of elevation accompanied by folding, flexing, and extrusion of andesite.
3. A second period of erosion—the pre-fault cycle.
4. Earlier faulting, during which the great faults of the Plateau region, such as Hurricane and Grand Wash faults, were originally formed.
5. Interfault cycle of erosion, during which the Mohave peneplain was formed.
6. Later faulting and final uplift of the High Plateau.
7. Erosion of Grand Canyon.

The history thus developed corresponds in many ways with that of western Arizona, but differs notably in some respects. The early Tertiary erosion in western Arizona seems to correspond in time with the Eocene sedimentation of the plateaus, and eruptions of andesite marked the close of the period of both provinces. There is, furthermore, no disagreement regarding the time of uplift and faulting immediately preceding the erosion of Grand Canyon, but further investigation is necessary before the subdivision of middle and later Tertiary time in the two provinces can be harmonized. Apparently, the great masses of rhyolite, 3,000 feet thick in western Arizona and presumably extruded at the close of the Miocene, were not found in southwestern Utah, and the long period of erosion which followed their extrusion, presumably during Pliocene time, seems to be included by Huntington and Goldthwaite in the time during which the Mohave peneplain was being formed, since according to them this cycle of erosion ended with the uplift of the plateau and the origin of Grand Canyon.

Since the Mohave peneplain is here used as a correlation horizon, it may be in place to inquire into its probable extent. As already stated, this peneplain, which in the Plateau region of southern Utah and northern Arizona is represented by the platform at the top of Grand Canyon, is here regarded as extending generally over northwestern Arizona. A similar peneplain has been described by Lindgren[a] in the Sierra region of eastern California, where he finds evidence of an extensive peneplain, formed presumably during the Miocene and covered in part by the younger auriferous gravels, and these in turn by rhyolites and andesites—a sequence which corresponds with that in northwestern Arizona. Other localities might

[a] Lindgren, Waldemar, Age of the auriferous gravels of the Sierra Nevada: Jour. Geology, vol. 5, 1896, pp. 881-906.

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be referred to in which mid-Tertiary erosion may correspond in time with the formation of the Mohave peneplain. In view, however, of the great distances between the various localities described and the difficulties of correlating periods of erosion, the most that can be said is that the available evidence points to the probability that the Mohave peneplain was one of great extent and may prove to be a valuable means of correlation.

WATER SUPPLIES.

SURFACE WATERS.

PRECIPITATION.

Little is definitely known of the rainfall in western Arizona. According to E. C. Murphy,[a] of the U. S. Geological Survey, the average annual precipitation for the region is approximately 5 inches. At Needles, Cal., records kept by the Weather Bureau since 1892 show an annual mean of 2.47 inches.

EVAPORATION.

Evaporation in western Arizona greatly exceeds rainfall. No records are available for the area described, but it probably does not differ very much from that at Yuma, Ariz., where the annual evaporation, as given by Murphy, is 82.32 inches.

STREAMS.

COLORADO RIVER.

Flow.—A gaging station has recently been established at Hardyville, near old Fort Mohave, for measuring the flow of Colorado River. Records, however, are already available for the last four years at Yuma, Ariz., which probably give most satisfactorily the volume carried by the lower Colorado.

Discharge of Colorado River at Yuma, Ariz.

	Total in acre-feet.	Mean in second-feet.
1902	7,960,189	10,970
1903	11,329,032	15,595
1904	10,109,004	13,922
1905	19,710,000	27,300
Average	12,277,056	16,947

Irrigable lands.—Although a large amount of water is available in Colorado River, the irrigable land is limited in amount and confined

[a] Personal communication.

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to the flood plains. According to Homer Hamlin,[a] of the Reclamation Service, the acreage is distributed as follows:

Irrigable land along Colorado River.

	Acres.
Cottonwood Valley	5,000
Mohave Valley	50,000
Chemehuevis Valley	20,000
Great Colorado Valley	200,000
Yuma Valley	100,000
	375,000

The ways and means of irrigating these lands have been investigated by the Reclamation Service, but except for the Yuma project, now under construction, no development has yet been undertaken.

Outside of the flood plains no lands within the area described are sufficiently low to be irrigated from the river. The broad valleys and detrital plains occupying so large a part of the region, although admirably adapted to agriculture in other respects, are too high to be economically supplied with water from Colorado River by any means known at the present time. In order to water the Hualpai or Detrital valleys it would be necessary to raise the water of the river about 2,000 feet, and the case is nearly as hopeless for the valleys farther south.

Dam sites.—Several dam sites have been selected along Colorado River by the engineers of the Reclamation Service, and much has been done in the way of investigation as far north as the Cottonwood Valley. Possible dam sites occur in Chocolate Canyon (fig. 13), Aubrey Canyon, at Bulls Head in Pyramid Canyon (Pl. IX), and at Eagle Rock in the Cottonwood Valley (fig. 7). In none of these localities, however, has bed rock been found sufficiently near the surface to warrant the construction of masonry dams. In Chocolate Canyon borings reached the depth of 138 feet; in Aubrey Canyon, 75 feet; in Pyramid Canyon, 100 feet. But in no case was the maximum depth of the old gravel-filled channel reached.

The canyons north of the Cottonwood Valley offer excellent opportunities for the construction of dams, but little has been done further than the selection of certain favorable localities. Several have been selected by the Reclamation Service, and others by private companies who contemplate using the water power in developing the mineral resources of the region. The questions involved are mainly of an engineering nature, but it may be in place here to describe certain geologic conditions that are likely to affect development.

In Recent time—the last epoch described under "Geologic history"—the river has been filling its channel, at least in its lower

[a] Personal communication.

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reaches. It is evident, therefore, that even in the newest channels, such as that at Bulls Head, bed rock is not to be expected as near the surface as it would be if the river were in an eroding stage. In other words, it is probable that the rock channel is deeper than the maximum depth of scour.

The flood-plain deposits, so conspicuous in the lower reaches of the river, become less conspicuous upstream, until in Black Canyon rapids of notable proportions occur. In the absence of soundings in the channel for bed rock farther north than Bulls Head, it is impossible to say that the channel is not filled in the northern portion of the region as it is farther south where soundings have been made. The swift current washes the fine material away and leaves large bowlders clogging the channel even where the grade of the river is steep enough to form dangerous rapids. It is the writer's impression that the river is flowing essentially on rock bottom through Black, Boulder, Virgin, and Iceberg canyons, with only such obstructions of bowlders as are incidental to variations in the river's power of transportation; in other words, that there is no permanent filling in the bottom of those canyons.

The deflection of the river previously described has resulted in the cutting of young channels in many places for short distances, as at Eagle Rock, Bulls Head, Great Bend, etc. It is in these young channels that bed rock is to be expected at the least depth. The relation, however, to the old débris-filled channel at the side may be such as to influence this depth. For example, at Bulls Head the depth to bed rock in the channel now occupied by the river might be greater near the edge of the old channel, owing to the fact that the new channel might coincide with some lateral wash of the old, while north of Bulls Head Rock, midway of the young channel, bed rock might be much nearer the surface. The depth to which a large river works is known to be great, although there is little information at present to indicate the maximum depth to which Colorado River works. The records of Missouri River, previously cited (p. 66), indicate the possibility that a depth of 73 to 100 feet, or even more in narrow channels, such as that at Bulls Head, is to be expected as a result of river abrasion alone.

Considering further the depth of scour, it is evident that the river will cut to a less depth in wide passages than in narrow passages where the current is swift. The narrow places are usually selected as dam sites on account of the presence of favorable abutments comparatively close together. It is possible that in certain cases the depth to bed rock in the wide part of a gorge, where the abrasive force is weak owing to a diminution of velocity, might be enough less than in the narrow parts, where the current is swift, to more than compensate for the greater length of a dam.

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BIG SANDY WASH AND WILLIAMS RIVER.

Big Sandy Wash has a small permanent flow, and Williams River furnishes water for the irrigation of a few ranches, but the floods of Williams River are evidently large. Water marks on the rocks and drift material lodged in the face of the canyon walls are seen at the height of 20 feet or more above the bed of the stream. The quantity of water discharged by Williams River is apparently sufficient to warrant the construction of a reservoir in the basin east of Williams Canyon. This basin is about 7 miles long and 5 miles wide, and the gorge forming a possible dam site is about 60 feet wide at the water line.

A reservoir at this place would be of comparatively little use in irrigation, as there is practically no irrigable land available. It might, however, be of great benefit in producing power for the development of the mineral resources. Rich deposits of gold, copper, and iron are known to occur in this region, but development is hindered or wholly prevented by the want of transportation facilities. The production of power, such as seems possible in this locality, might be the means of developing a rich mining district.

UNDERGROUND WATERS.

SURFACE INDICATIONS.

In many places throughout the Southwest the unconsolidated deposits filling the old valleys and intermontane basins are saturated with water, and the hope was entertained that this might be the case in the area here described. The geography of the region, however, is not favorable for the accumulation of large quantities of underground water, nor for the retention of such as might accumulate. The rainfall is slight and no large quantities can be derived from streams. Colorado Canyon on the north and west forms an effectual outlet for waters which might otherwise accumulate in the gravels.

From surface indications the Hualpai Valley would seem to have an underground water supply. It is an undrained basin into which Truxton Creek empties, and contains standing water for considerable periods. Only one well has been bored in the valley, at its northern extremity in Hualpai Wash. The absence of water in this well is not considered proof that water may not exist near the surface in the center of the valley.

In the other valleys and plains of the region the prospect is not encouraging. There is little opportunity for the accumulation of water in the gravels of the Cactus Plains, because of drainage into Colorado River to the west and Williams Canyon to the north. Conditions in the McMullen Valley are slightly more favorable, but water is found only at depths of 100 feet or more. No wells are reported from the plains south of Harrisburg.

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WELLS.

Nelson.—The well at Nelson, Ariz., is 1,043 feet deep. At 516 feet a little water was found, and in the sandstone near the bottom a larger supply was encountered; but the available quantity has not been ascertained. The formations passed through are as follows:

Log of railroad well at Nelson, Ariz.

	Feet.
Cemented detritus	0– 44
Limestone (Redwall)	44– 396
Sandstone and shale (Tonto)	396–1,043

Peach Springs.—A well at Peach Springs, Ariz., is 920 feet deep. A small amount of water was encountered somewhere in the lower half, but the horizon is not known. Water stands at a depth of 413 feet, and a preliminary pumping test yielded 25 gallons per minute, or 14,000 gallons per day of twenty-four hours. This is insufficient for railway use, and the well is to be sunk deeper. The formations passed through are as follows:

Log of railroad well at Peach Springs, Ariz.

	Feet.
Cemented gravel	0–200
Limestone (Redwall)	200–560
Shale (Tonto)	560–920

Hackberry.—There are several dug wells at Hackberry, Ariz., in or near the bed of Truxton Creek. They penetrate through the detritus and encounter granite at a depth of about 70 feet, where a limited flow of water is obtained. The well at the railway station is taxed to its extreme limit in supplying 80,000 gallons in twenty-four hours, or 55 gallons per minute.

Kingman.—There are about 60 wells in the town of Kingman. A few of these are dug, but most of them are drilled. They are from 120 to 200 feet in depth, according to the difference in surface elevation. The water occurs in a bed of volcanic tuff about 30 feet thick, which rests upon the granite. An abundance of water is obtained from these wells to supply the needs of the railroad and the town.

Gold Basin.—Two wells 500 and 700 feet deep were drilled several years ago in Gold Basin at the northern end of the Hualpai Valley, about 50 miles north of Kingman. Nothing but detrital material was penetrated, and no water was encountered.

Drake.—The well at Drake, in the Sacramento Valley, is 687 feet deep and penetrates to bed rock. Water was encountered at a depth of 430 feet in "gray granite" and rose 30 feet. (This material is undoubtedly granitic wash, cemented by carbonate of lime. Cemented material of this kind is common in the Quaternary deposits throughout the arid regions. The yield of the well has not been determined.

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Log of railroad well at Drake, Ariz.

	Feet.
Sand and bowlders	0– 45
Brown sand	45– 90
Bowlders	90–160
Brown sand	160–178
Sand and gravel	178–223
Black lava	223–308
Yellow sand	308–368
Black lava	368–408
Flint	408–414
Black lava	414–419
Gray granite	419–475
Black lava	475–483
"Gray granite," water bearing	483–537
Clay	537–578
Disintegrated granite	578–603
Solid granite	603–687

Yucca.—There are two deep wells at Yucca, situated near Sacramento Wash. The first was drilled in 1889 and has been in operation since that time. The amount of water obtainable was not sufficient for the needs at that point, and a second well has been put down to a depth of 1,004 feet. Water is said to have been encountered at a depth of 310 feet, but when measured by the writer in the new well it was standing at a depth of 346 feet. No special water-bearing stratum was encountered below the first, and the additional supply is obtained by slow seepage through the sand and gravel. The material encountered is as follows:

Log of railroad well at Yucca, Ariz.

	Feet.
Cemented sand and gravel	0– 370
Clay	370– 455
Gravel	455– 555
White sand	555– 905
Granite	905–1,004

Haviland.—The well at Haviland is 505 feet deep and is in volcanic material most of the way. Water was encountered at a depth of 248 feet and rose 48 feet. The well yields 60,000 gallons of water per day, or about 42 gallons per minute. The material penetrated is as follows:

Log of railroad well at Haviland, Ariz.

	Feet.
Bowlders	0– 12
Lava	12–260
White volcanic tuff	260–505

Big Sandy Valley.—Several wells dug in Big Sandy Wash encountered water 15 to 75 feet below the surface, according to locality. It is reported that a few years ago water was sufficiently near the surface to seep into the lower places along the bottom of the valley,

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where it was used for irrigation; but during the last few years this seepage has disappeared.

Harrisburg.—Near Harrisburg, at the point where the wash draining the McMullen Valley passes through the constriction between the mountains, a centrifugal pump has been established, and water is obtained in sufficient quantities to irrigate a small ranch. This supply is local and limited in amount.

Other wells.—At a number of places in McMullen Valley, in the Cactus Plain, and in the plains of the southern extremity of the region, wells were reported; but nowhere was ground water encountered in sufficient quantities or near enough to the surface to warrant any attempt at development for irrigation.

Records of railway wells in northeastern Arizona.

Location.	Depth.	Diameter.	Year completed.	Depth to water.	Water raised by—	Amount raised in 24 hours.	Remarks.
	Feet.	*Inches.*		*Feet.*		*Gallons.*	
Haviland	505	12	1901	200	Air lift	60,000	
Yucca No. 1	534	10	1889	346	do	[a] 90,000	36,000 gallons per day is all that can now be pumped.
Yucca No. 2	1,004	13	1903	346	do	Not tested.	
Kingman	120–200	Dug.	(?)	(?)	Steam pump		
Drake	684	12	1901	400	Air lift	Not tested.	
Hackberry	70	Dug.	(?)	66	Steam pump	80,000	
Peach Springs	920	13	1903	413	do	14,000	Not satisfactory; will be sunk deeper.
Nelson	1,043	13	1902	490		Not tested.	Water struck at 516 feet.

[a] When tested.

DEEP-WELL TEMPERATURES.

Temperature readings taken at two of the deep wells are given in the following table. The results obtained at Yucca are probably more satisfactory than those at Nelson, as conditions were more favorable for satisfactory observation. At Nelson the thermometer was not in the water at the upper horizon tested, while at Yucca it was under water at both horizons. The increase of temperature downward in the Yucca well was 1° F. for 55+ feet. That in the Nelson well was 1° F. for 68+ feet.

Temperatures of water in wells at Yucca and Nelson, Ariz.

Location.	Surface elevation.	Total depth.	Depth to water.	Date of observation.	Surface temperature at time of observation.	Depth at which temperature was taken.	Temperature.
	Feet.	*Feet.*	*Feet.*		°F.	*Feet.*	°F.
Yucca, Ariz.[a]	1,804	1,004	346	Sept., 1903	98	1,004	90.5
Do	1,804	1,004	346	do	98	455	80.6
Nelson, Ariz.[b]	5,200	1,043	490	do	75	1,040	73.4
Do	5,200	1,043	490	do		200	61.2

[a] General region volcanic. Drilling suspended three months previous to observation.
[b] In limestone region at edge of plateau. No work done on well for several months previous to time of observation.

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NOTES ON THE IGNEOUS ROCKS OF WESTERN ARIZONA.[a]

By ALBERT JOHANNSEN.

PRE-CAMBRIAN CRYSTALLINES.

The oldest of the volcanic rocks in northwestern Arizona are granites (A–6, A–44).[b] According to Lee, they occur below the effusives throughout the entire area, and in the cliffs to the east are overlain by the same series of Cambrian rocks which in the Grand Canyon section is called the Tonto formation. Over the whole area the fact that the granite is an older and not a younger intrusive is clearly indicated by the occurrence of dikes and veins within it which do not extend through the overlying rocks. The upper surface was planed nearly to a base-level and the effusives generally overlie it in horizontal sheets.

Much granite occurs in the area. The rock is red to gray in color, is usually coarsely crystalline, and is much cut by dikes and veins. Here and there in faulted regions, the rock is highly gneissoid, while in other places the mass passes, by easy transitions, from the normal rock to the schistose. The specimens are very similar in mineralogic character, though no thin section of the normal type was examined. Megascopically A–6 is fine and schistose, and consists of black and white bands of feldspar and biotite. A–44 is dark red in color and is very compact. Under the microscope the former is schistose, hypautomorphic-granular, while the latter is similar but without showing schistosity. In both, the minerals are feldspar, less quartz, and still less biotite. Zircon and apatite are accessory. The feldspar is chiefly orthoclase, which is now and then intergrown with plagioclase in the form of microperthite; a little microcline and a little oligoclase or andesine occur. The biotite occurs in shreds and patches (subparallel in A–6) and is in many specimens considerably altered to iron oxide, so that it is black and opaque. Normally the pleochroism of the biotite is $\mathfrak{a}$ = light green and $\mathfrak{b}$ = dark green. Zircon occurs as short, stout, rounded grains, and apatite occurs

[a] The specimens here described were collected by Mr. Lee and the geologic relations are given from his observations. The report on the examination of the thin sections was made in 1906.

[b] References are to original specimen numbers; see list, p. —.

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both in small and thin and in large and stout prisms, the latter being sometimes irregular in form. The accessories occur within both the quartz and the feldspar.

Farther to the south, in Williams Canyon, the banding of the underlying rocks becomes much more marked, giving long-drawn-out black and white bands (A–49), for which reason the name of "Banded Canyon" is applied to the gorge through which Williams River flows. Lee describes the rock as apparently continuous with the granitic rocks to the north, although the transition was not followed. Megascopically the rock is aphanitic, black and white banded, the black bands occasionally showing white phenocrysts and rounded inclusions. Under the microscope the texture is markedly schistose. The constituents are irregular rounded grains, very variable in size, of hornblende, orthoclase, some plagioclase, and a little quartz. There is much chlorite, and a little epidote and titanite.

EFFUSIVE ROCKS.

OLDER ANDESITE.

Some time during the Tertiary period, after the Paleozoic and Mesozoic sediments had been removed from the area and the underlying granite deeply eroded, began a period of volcanic activity. The earliest erupted rocks of which traces now remain were andesites, a remnant of which occurs at Black Mesa, north of Boundary Cone (A–11). It here appears to underlie and is cut by dikes of rhyolite (A–12). This is the only area where any eruptive rock is definitely known between the rhyolite and the granite. In several places the andesite (A–40, A–41) rests directly upon the granite, but no rhyolite occurs above it, and consequently the later flow and the intervening rocks may have been eroded. The andesite from Black Mesa is, then, as described above, beneath the rhyolite and is cut by it; and since within the rhyolite flow breccia from various parts of the region andesite fragments occur, it is very probable that this rock is in place and is older than the rhyolite.

Megascopically this andesite (A–11) is dark reddish gray in color and shows numerous white phenocrysts in a fine aphanitic groundmass. Under the microscope the texture is porphyritic and sempatic. The phenocrysts are fairly regular laths, some of which are partially and some completely altered. The partially altered phenocrysts are plagioclase, which still show indistinctly the original twinning, but the extinction angle can not now be determined. They have an index of refraction higher than Canada balsam, and are much altered to calcite, sericite, and kaolin. Besides these, there are fewer chlorite pseudomorphs and still less magnetite. The chlorite pseudomorphs are lath-shaped and are very similar in form and size to

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the plagioclase laths. None of the original mineral remains, and there is occasionally a center of calcite. Possibly they are pseudomorphs after hornblende. The magnetite occurs in irregular and corroded grains and is usually surrounded by a rusty rim. By incident light the surface appears black and metallic, but with rusty patches, the smaller grains sometimes having the entire surface rusty. The groundmass is anisotropic and full of alteration products, and consists of xenomorphic laths and patches of feldspar, much altered to kaolin, sericite, and chlorite, and of magnetite grains and dust. It has the appearance of having originally contained small lath-shaped feldspars. Whether there was also originally orthoclase is indeterminable. Kaolin occurs as a secondary product in semiopaque patches in the groundmass and in the feldspar phenocrysts.

RHYOLITE SERIES.

Resting upon the andesite at Black Mesa, and in other places directly upon the granite, is a thick series of rhyolites, rhyolite flow breccias, and tuffs, which reach a thickness of 3,000 feet or more. They are all clearly older than some of the andesites (107, A–18) and older than all of the basalts. In the field the general appearance of the rhyolite is white to pink, making a sharp contrast with the underlying granite and the overlying andesites and basalts. Usually the flows are massive, often brecciated, and often very coarse agglomeratic, with angular blocks having a maximum diameter of several feet. In places these included fragments are rounded and the bedding of the tuffs is horizontal. No attempt was made to separate the rhyolite into distinct flows, as might be possible with more detailed study. The areas at which the specimens studied were collected being in many cases far removed from the others, it is impossible to correlate the relative geologic positions.

The rhyolites may be divided into four groups—flow breccia, ash, normal rhyolite, and spherulitic rhyolite.

In general the megascopic appearance of the rhyolite flow breccia is white to pink, with included irregular dark-brown fragments, usually small. Under the microscope the appearance of all (101, A–13, A–19, A–35) is very similar. The rock consists of a glass full of bubbles, often in flow lines and sometimes devitrified. It is full of irregular and broken fragments of orthoclase, quartz, sometimes a little biotite, microcline, apatite, plagioclase, and hornblende, several or all, and usually some iron ore. Some of the specimens are altered and contain, besides iron oxide, much calcite. Besides the mineral fragments contained in the glass, there are irregular dark and altered inclusions of andesite, which clearly indicate that there was a previous eruption of a basic rock. No correlation is possible, however,

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between these fragments and the single specimen obtained from the flow below the rhyolite at Black Mesa. There may have been, and probably were, volcanic eruptions previous to that of the rhyolite, of which now no trace remains, and the fragments in the rhyolite flow breccia indicate that the andesite was much more extensive than at the present time.

West of Boulder Canyon in Colorado River is a volcanic tuff (A-39). It is gray to pink in color, ashlike, gritty, very friable, and fine grained, and occurs in horizontal beds. Under the microscope it is tuffaceous and is composed chiefly of small angular glass fragments, needle-like and in flakes, and contains a few very small and irregular quartz grains.

Compact normal rhyolite (117, A–7, A–12, A–43) occurs within the rhyolite series, but no attempt was made to find the relationship which may exist between these flows and the sheets of breccia, flow breccia, and so on, in which it occurs. Megascopically these rocks are white or pink and sometimes banded. Under the microscope a glassy flow texture is plainly seen in one of the rocks (A–43), while in others (117, A–7), although now devitrified, the flow texture can be clearly made out. In 117 the original flow lines of the groundmass show in polarized light by the fact that there are larger and more numerous quartz particles along certain lines, while areas between these lines are much finer grained, and very often the centers of these areas are almost entirely isotropic. In the specimen from Black Mesa (A–12), from the region where the andesite (A–11) underlying the rhyolite was obtained, no flow texture can now be made out. It is completely devitrified and is now an aggregate of quartz and feldspar. According to Lee, this rhyolite occurs in dike-like intrusions and in sheets overlying the andesite, a fact which clearly proves the older age of the andesite, provided that the intruded and overlying rocks are both like the specimen (A–12). All of the sections are perpatic. In some, fragments of orthoclase, a little plagioclase, and some quartz occur, and in others the original phenocrysts are much altered. Magnetite and zircon are accessory, and calcite and zeolites secondary minerals. Chlorite, from an original femic mineral, occurs in 117.

Two of the rhyolite specimens are spherulitic (A–1, A–8). Megascopically these specimens are pink, spherulitic, and full of large irregular cavities, occasionally filled with quartz crystals. Under the microscope the rock shows very few phenocrysts of orthoclase, plagioclase, and biotite, and rather rare magnetite crystals in a spherulitic groundmass. In one specimen (A–8) the entire rock is filled with trichites, generally in hairlike bunches. Sometimes margarites occur—that is, hairlike strings of globules; and in places microlites appear in schools. In the specimen from Wickenburg (A–1) there is, in the

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groundmass, besides the spherulites, a quartz-orthoclase aggregate in finger-like interlocking particles. The rock is rather dark with feritic material, and there is considerable kaolin and other alteration products. In the rays of the spherulites there is often a deposit of red hematite or limonite, and cubes of what may have been magnetite show a slight red edge in transmitted light, as though altered to limonite.

YOUNGER ANDESITES.

Definitely in place in a number of localities above the rhyolite is an andesite (107, A–18). This is much more limited in extent than the earlier flow. A number of other andesites which occur in the area either rest directly upon the granite (A–40, A–41) or are in masses isolated from the other effusives, so that no relationship is seen (112, A–2, A–42); they may belong either to the upper flow, the underlying rhyolite having been eroded, or to the earlier flow. In the field all of the andesites are of a dark-red to brown color, are often vesicular, and are often very hard to distinguish from the overlying olivine basalts.

The two specimens (107, A–18) from above the rhyolite are dark reddish black in color and are vesicular, with more phenocrysts in A–18 than in 107. Under the microscope the two rocks are very similar in appearance. Both of them are porphyritic-intersertal in texture and contain more phenocrysts than groundmass. The phenocrysts occur in two generations and consist of plagioclase (andesine to labradorite), augite, and magnetite. The larger plagioclase crystals occur as irregular fragments, often zonal, while the smaller occur in perfect laths. There is much less augite than plagioclase. This also occurs in two generations, and in each case is less in amount than the corresponding generation of plagioclase. Two generations of magnetite, less in amount than the augite, occur in quadratic and irregular crystals and grains. Of these the larger crystals are less in amount and the grains are smaller than the second generation of augite, and the small crystals are very small and are scattered through the groundmass in isometric crystals. They occasionally occur in the augite, but very rarely in the feldspar. The groundmass in both specimens is isotropic and consists of brown glass full of magnetite—so much in A–18 that it is nearly opaque.

Specimens A–40 and A–41, from sheets in the walls of Black Canyon, are augite andesite; possibly the latter at one time contained olivine; if so, it was an olivine basalt. Megascopically they are medium dark red-brown in color, with more or less black and white phenocrysts in an aphanitic groundmass. Under the microscope they are porphyritic and sempatic. The phenocrysts of 40 consist of broad, irregular laths, and the groundmass is apparently a devitrified glass, full of

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dust and grains of magnetite and hematite. Specimen 41 has phenocrysts of plagioclase, somewhat greater in amount than augite and much greater than some red-brown pseudomorphs which may be altered biotite or olivine. The groundmass in this specimen is in laths and irregular patches, much of which is definitely plagioclase. Besides the feldspar, much black and red iron oxide and shreds of augite and dark altered biotite (?) occur.

A–42 is a biotite-augite andesite from a sheet forming Eagle Rock, near Little Round Island, and is similar in character to the two preceding. The phenocrysts, less in amount than the groundmass, are, in the order of their importance, plagioclase, biotite, diopside, and magnetite. The plagioclase is andesine to labradorite. The biotite has a peculiar deep red-brown color, is pleochroic with b=brownish red and a=greenish yellow, and has much the appearance of basaltic hornblende. It has, however, parallel extinction, gives a uniaxial interference figure, shows parallel cleavage in laths, has the "bird's-eye maple" surface, and is optically negative. It always has a dark rim of magnetite. The pyroxene is pale green in color, is nonpleochroic, has an extinction of about 40°, and has good cleavage—parallel in laths and at right angles in basal sections. It is diopside. Both the plagioclase and the pyroxene are much altered to calcite. The groundmass is yellowish to red, cloudy, and apparently partially devitrified glass full of red ore dust. Most of the anisotropic part of the groundmass is spherulitic or contains innumerable microlites.

South of Seligman there is a hypersthene andesite (113). This is from the lower of two flows, the upper of which is darker and may be basalt, though no specimen was examined. Megascopically 113 is a dark-gray rock with white patches and occasional calcite fillings in cavities. Microscopically the texture is porphyritic and dopatic. The phenocrysts are either thin or broad laths, and the groundmass is hypautomorphic. The phenocrysts, in the order of their abundance, are plagioclase, augite, and hypersthene. The feldspar occurs in both large and small laths. The stout crystals are not twinned and are always zonal; the narrow crystals are usually twinned and give an extinction between 20° and 25°, or that of andesine. In the zonal feldspars the index of refraction at the center is higher than at the rims; the interference figures are positive, and show a comparatively small value for 2E. This excludes all the feldspars but andesine and labradorite. Since the rims have a lower index but are still positive in character, it shows that the feldspar is either labradorite or andesine or both, and that the interior is more basic than the exterior. The femic minerals consist of very irregular grains of a greenish pyroxene with a high extinction angle—augite; and another pyroxene occurring in elongated prisms with longitudinal cleavage, having parallel extinction, showing high interference colors, optically negative, and

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slightly pleochroic in pink and green tones—hypersthene. Magnetite occurs in grains which, in size, grade into the groundmass. There is no definite line, and it is in such irregular grains that it may be included with either the phenocrysts or the groundmass. Exclusive of the femic minerals, the groundmass is made up of xenomorphic areas and laths of feldspar which are probably of the same kind as the large phenocrysts. The xenomorphic feldspar has an index of refraction greater than Canada balsam and is consequently plagioclase, but the areas are so small that the kind is indeterminable. Besides the feldspar there is an isotropic substance which occurs in very small anhedrons and which may be glass or a zeolite. The groundmass is full of magnetite dust and there is an alteration product in the cleavage cracks of some of the feldspars which is anisotropic and has an index of refraction less than Canada balsam. It is a zeolite.

Twenty-five miles west of Congress Junction there occurs a coarse breccia formed of large angular blocks cemented with red material. Megascopically the specimen (A–2) has a red compact groundmass, and there are phenocrysts of hornblende forming about one-eighth of the mass. Microscopically the texture is porphyritic and perpatic. The phenocrysts are hornblende, much less plagioclase, and still less biotite. The hornblende is very peculiar in several ways. It has a very low extinction angle, generally appearing as parallel, the largest found being only $3\frac{3}{4}°$—that is, c: $\mathfrak{c}$ is circa 4°. The pleochroism is also peculiar. For $\mathfrak{a}$ it is a greenish yellow, while for $\mathfrak{c}$ it is a deep red-brown. Absorption $\mathfrak{c} > \mathfrak{a}$. The elongation is parallel to $\mathfrak{c}$, and therefore it is positive, while the optical character of the mineral is negative. Surrounding the mineral there is always a dark rim of iron oxide. This is usually black, but occasionally it shows a red tone. The cleavage is good, parallel to $\dot{c}$ in lath-shaped sections, and in basal sections the usual amphibole cleavage. The mineral is basaltic hornblende. The feldspar is generally zonal and is positive in character. It is between andesine and labradorite. Actually the amount of plagioclase that occurs is much less than the amount of hornblende, but the phenocrysts of feldspar have either weathered out or been ground out in preparing the thin section. Apparently they were originally much more numerous and both longer and broader than the hornblende. Biotite occurs in a very few long, thin flakes. It has dark rims, and magnetite is included along the cleavage lines. Pleochroism is brownish to greenish. Magnetite occurs in irregular grains. The groundmass consists chiefly of laths of plagioclase, which have an extinction angle of 30° and are consequently labradorite. Between the feldspar laths there is a much iron-stained substance which is probably glass. Iron oxide occurs in the form of very fine dust and in patches, producing the red color of the rock.

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OLIVINE BASALTS.

Resting upon the andesite, upon the rhyolite, or even upon the granite, and also upon and within Quaternary gravels, depending upon the amount of erosion that has taken place, is a series of olivine basalts—the youngest lava in the region. There are at least three flows of this, but it is impossible, from the amount of field work done, to correlate the different sheets in different parts of the area. Five or six varieties can be distinguished under the microscope, but they may be but different phases of the same rock, a greater or less development of olivine or a coarser or finer groundmass forming the various types. This difference in appearance may be seen even in two sections (as 110, 111) which have been collected near together from undoubtedly the same flow and which show different characters. Five types may be distinguished, according to the fineness of the groundmass: (A) 110, 111, 3, 45; (B) 15, 16, 24, 25, 27; (C) 37, 46; (D) 22, 23; (E) 30, 34.

Occasionally the field relation can be seen; thus, 24 is from a sheet overlying 25; 15 is from a sheet intruded into the rhyolite and lifting it; and 16 is from a sheet above the rhyolite.

In the field the general appearance of the basalt is black or very dark red. In general it is darker in color than the underlying andesite and is often vesicular and ropy. Where it rests upon the rhyolite it forms sharp cliffs. In many places it forms flows in erosion valleys, and though actually lower in position, is higher geologically.

Megascopically the hand specimens are compact and vary in color from black through dark gray to dark brownish red. Occasionally there is a somewhat banded arrangement—that is, alternating bands of a lighter color. Under the microscope the texture of all the specimens is porphyritic, with a groundmass generally trachytic and with the small plagioclase laths in subparallel position. In general the phenocrysts of the rock are olivine, or, when other minerals occur, they are greatly in the minority. In four specimens, however (22, 23, 45, 46), the phenocrysts are chiefly plagioclase.

In specimens 22 and A–23 the plagioclase phenocrysts are greatly in excess of the olivine, and the latter are much in excess of the augite. The groundmass is much coarser than A–45 and consists of plagioclase laths and areas, less augite grains, and still less magnetite. The feldspar is labradorite. Olivine is very much altered to a red-brown mineral which may be iddingsite or an iron-stained serpentine. Some of the olivine is fresh and shows simply an altered rim or altered center.

A–45 is perpatic, has a much finer groundmass than either A–22 or A–23, and does not contain prominent augite grains in the groundmass. The constituents, in the order of their abundance, are plagio-

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clase, augite, olivine, and magnetite. The feldspar is labradorite or andesine. The olivine occurs in doubly terminated crystals, only slightly altered.

A–46 is very similar to A–23, except that the difference between the size of the grains in the groundmass and the phenocrysts is not so great.

Specimens 110, 111, and A–3 are similar to A–45, in having a very fine groundmass. The phenocrysts of 110 and 111 are augite and biotite in about equal amounts, and less of a completely altered red-brown mineral which may have been olivine. The biotite and augite are usually altered in part also, and are surrounded by black rims. The groundmass consists of lime-soda feldspar laths in subparallel position in swirling eddies—a trachytic texture. There are also a few small irregular patches in the groundmass which have an index of refraction less than Canada balsam and are faintly anisotropic. They may be analcite, but are too small to determine. Calcite occurs as a secondary product, and magnetite occurs in a few large crystals as well as in small grains in the groundmass.

In A–3 there are more augite phenocrysts than olivine. The latter is altered, completely or in cracks, to a red-brown mineral, which has an index of refraction much less than that of the olivine and is fibrous. It appears to be iron-stained serpentine. Magnetite occurs within the olivine in rather large grains and crystals. The groundmass consists of laths of labradorite in broad flow lines swirling around the olivine phenocrysts. Almost invariably they are twinned according to the albite law, and show an extinction angle in the neighborhood of 30°. Between the feldspar laths is much augite, pale green in color, and occurring in irregular grains, never in well-formed crystals or laths. Somewhat less in amount is magnetite, which occurs in cubical and irregular sections. Less in amount than the magnetite and, like it and the augite, occurring in irregular grains between the feldspar laths, is a reddish-brown mineral which has an index of refraction apparently greater than the augite. The grains are small and irregular, so that the determination is impossible. It appears to be partially altered olivine.

Somewhat coarser in texture under the microscope than the above are A–15, A–16, A–24, A–25, A–27, A–37. Of these, A–15 and A–16 have phenocrysts of olivine, augite, and plagioclase, with hornblende and biotite also in A–16. The olivine phenocrysts are generally entirely altered to a brownish-red serpentine and are usually ground out in the centers in preparing the section. The groundmass of A–15 is a dark glass full of small laths of plagioclase, laths of augite, and grains of red iron oxide, while A–16 has a groundmass of dark glass full of innumerable small feldspar laths and microlites and magnetite dust.

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A–24, A–25, A–27, and A–37 are very similar in appearance. The texture of all of them is porphyritic, with phenocrysts of olivine and a groundmass made up of laths of feldspar and grains of augite and magnetite and glass full of magnetite dust. The amount of glass is small and fills spaces between the plagioclases, but these spaces are very few and hardly show in the thickness of the section. The olivine phenocrysts are rather fresh, being generally altered only around the rims. Secondary calcite is common.

A–37 has more plagioclase than A–24 and the olivine is entirely altered to a dirty brownish-black substance.

A–30 and A–34 are porphyritic, with irregular rounded to angular crystals of olivine which are perfectly fresh. Some magnetite may be classed with the phenocrysts. The groundmass consists of long, narrow laths of labradorite with extinction angles of from 32° to 35°, and a less amount of a purplish, very slightly pleochroic augite, which fills the interspaces. The augite is not in typical ophitic form, but in irregular laths which fill the interstices. Generally it is very fresh, although there are patches of serpentine in the groundmass, some of which is definitely derived from olivine. Within the augite there is a great deal of magnetite in strings and in skeleton crystals, in beautiful branching forms.

DIKE ROCKS.

OLIVINE DIABASE.

Cutting the rhyolite at the eastern edge of Black Mesa, in Gold Roads Pass at Mud Spring, is a large dike, some 25 feet in thickness, of olivine diabase (A–14), apparently connected with a dark sheet which overlies the rhyolite. Megascopically the rock is dark in color and is rather coarsely granular. Under the microscope it has a typical ophitic texture and there is more feldspar than augite. The feldspar occurs in twinned laths with a maximum extinction angle of 31°, and is labradorite. It is very fresh, although occasionally it contains serpentine in cleavage cracks. Fresh augite in less amount than the plagioclase fills the interspaces between the feldspar laths. It is pale purple in color, and is nonpleochroic or very slightly pleochroic. It contains a small amount of iron oxide in extremely fine particles. Olivine, less in amount than the augite, occurs in irregular rounded grains, mostly small, though some are large. Some of the olivine is altered to serpentine, chlorite, and red iron oxide around the edges and in cracks. Magnetite occurs in still less amount and in irregular grains.

RHYOLITE PORPHYRY.

At the base of Boundary Cone is a plug, or dike from a plug, of rhyolite porphyry (A–10). Megascopically it is a pink, fine-grained

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rock, with quartz and feldspar phenocrysts. Under the microscope the texture is porphyritic and dopatic. The phenocrysts are large, occasionally somewhat corroded, and the groundmass is xenomorphic-holocrystalline. The phenocrysts are orthoclase, greater in amount than quartz, and much greater than acid plagioclase. The plagioclase occurs in but few crystals; it has, in part at least, an index of refraction less than Canada balsam, and is probably all albite. The groundmass is a quartz-feldspar aggregate with much hematite. Secondary kaolin and sericite are derived from the feldspar, and the red iron oxide perhaps from magnetite.

ROCK SAMPLES FROM NORTHWESTERN ARIZONA.

Following is a list of rock samples collected in northwestern Arizona with the original specimen numbers:

A-6. Granitic gneiss from south end of Hualpai Mountains.
A-10. Granite porphyry from base of Boundary Cone west of Black Mesa.
A-44. Biotite granite from mouth of Williams River.
A-49. Granite gneiss from Williams Canyon.
101. Rhyolite flow breccia from Lost Basin, about 5 miles south of Colorado River, in a depression of older crystalline rock.
A-35. Rhyolite breccia from Temple Bar.
A-7. Rhyolite from southern end of Black Mesa, at base of cliffs.
A-39. Rhyolitic tuff from Colorado River west of Boulder Canyon.
A-12. Rhyolite from Black Mesa, at Gold Roads.
A-13. Rhyolitic tuff from Black Mesa, in pass east of Gold Roads.
A-19. Rhyolitic tuff from Black Mesa, at summit of Union Pass.
A-43. Rhyolitic tuff from bluffs of Colorado River in Chemehuevis Valley.
A-2. Hornblende andesite from southern end of Aquarius Mountains, a few miles north of Date Creek.
A-11. Andesite from Black Mesa, north of Boundary Cone.
A-40. Andesite from north end of Black Canyon.
A-41. Andesite from south end of Black Canyon.
A-42. Andesite from Eagle Rock, near Little Round Island.
107. Andesite from coyote holes northwest of Kingman, at western edge of mesa.
A-18. Andesite from a sheet above the rhyolite 2 miles northwest of Kingman.
110, 111. Basalt from a flow sheet 300 feet thick resting on top of 400 feet of varicolored ash and breccia at mouth of White Cliff Creek.
112. Andesite resting on granite at top of Cottonwood Cliffs near mouth of Cottonwood Creek, 1,200 feet above Nos. 110 and 111.
A-3. Olivine basalt from a sheet in the detrital beds of Santa Maria Canyon, near mouth of Big Sandy Wash.
A-15. Basalt intruded into the rhyolite 1 mile west of Kingman.
A-16. Basalt from a flow sheet above the rhyolite 1 mile west of Kingman.
A-27. Olivine basalt from a sheet above the andesite near Kingman.
A-30. Olivine basalt from a columnar sheet resting on the Temple Bar conglomerate north of Colorado River in Grand Wash.
A-34. Olivine basalt from a flow sheet within the Temple Bar conglomerate near Greggs Ferry.

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A–14. Olivine diabase from the eastern edge of Black Mesa, at meadow spring in Gold Roads Pass; dike cutting the rhyolite.
A–22. Olivine basalt from Mud Spring at eastern edge of Black Mesa.
A–23. Olivine basalt from north end of Cerbat Mountains.
A–24. Olivine basalt from a sheet resting upon granite east of Cerbat Mountains.
A–25. Olivine basalt from a sheet resting above A–24.
A–45. Basalt from a sheet 800 feet thick covering the Temple Bar conglomerate in Williams Canyon.
A–46. Olivine basalt near Planet, in Williams Canyon.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 353

GEOLOGY

OF THE

TAYLORSVILLE REGION, CALIFORNIA

BY

J. S. DILLER

WASHINGTON
GOVERNMENT PRINTING OFFICE
1908

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OLOGY OF THE TAYLORSVILLE REGION OF CALIFORNIA.

By J. S. DILLER.

INTRODUCTION.

LOCATION AND EXTENT.

e Taylorsville region is a triangular area on the northern end of Sierra Nevada in California. It lies in the northeastern angle een the fortieth parallel and the one hundred and twenty-first dian, and embraces the northeastern part of Plumas County the adjacent portion of Lassen County, comprising about 750 re miles. The greater portion of the population is in Indian y, Genesee Valley, and North Arm. The town of Taylorsville, which the whole region is here named, is approximately in its er.

LINE OF THE GEOGRAPHY AND GEOLOGY OF THE REGION.

orthern California belongs to five topographic provinces, con- g of three mountain ranges—the Coast, Cascade, and Sierra ada—and two valleys—the Sacramento and the valley of the ior, which forms a part of the Great Basin. The Coast Range des the Klamath Mountains, which occupy the northwest corner e State. Lassen Peak, the southern end of the Cascade Range, between the Klamath Mountains and the Sierra Nevada, as n in Pl. I, giving them apparent continuity, but in reality sepa- g them, for the Cascade Range is wholly of volcanic origin and ents marked contrast to the Sierra Nevada and Klamath Moun- s. The Taylorsville region belongs to the Sierra Nevada, but is ered on the north by the Lassen Peak portion of the Cascade ge and on the east by the Great Basin.

he main body of the Sierra Nevada has but one crest, with a long, le slope southwestward to the Sacramento Valley and a short, p slope northeastward to the Great Basin. It appears as a great k of the earth's crust tilted toward the southwest. The northern

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end of the range, beyond Lake Tahoe, has three crests, those of Clermont Hill ridge, Grizzly Mountains, and Diamond Mountain, and each crest has a valley at its northeast base. The western crest, the Clermont, is continuous with the main crest of the range north of Lake Tahoe. American and Mohawk valleys lie to the northeast. The other two are crests of blocks that have been added in the Taylorsville region on the northeast of the main block, as shown in fig. 1, causing the eastern face of the range to advance in that direction nearly to Honey Lake.

The geology of the Sierra Nevada is complex. Although the range is the result of an uplift that occurred in comparatively recent geologic time, the material of which it is composed involves a long and

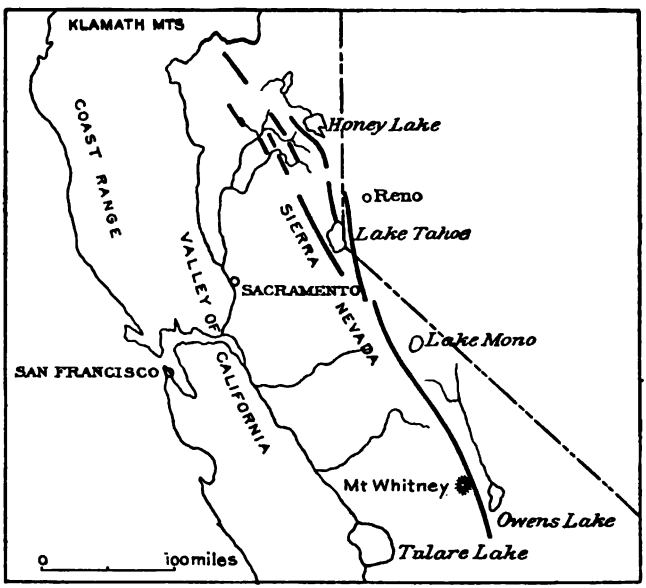

FIG. 1.—Faults limiting the Sierra Nevada on the northeast. Heavy black lines indicate position of faults.

varied succession of deposits of sedimentary and igneous rocks, extending from early Paleozoic to the close of Jurassic time. During that long period the Sierra Nevada region was beneath the sea, receiving sediments from a land area along the eastern border in Nevada. About the close of the Paleozoic era the rocks were compressed and folded, and were intruded to some extent by igneous rocks, so that the Mesozoic sediments, which are of much less bulk than the Paleozoic, were deposited upon the latter unconformably. At the close of the Jurassic the Sierra region was again greatly compressed and uplifted, forming a prominent mountain range. The rocks were folded and rendered schistose or platy in connection with the intrusion of great masses of granitic and other igneous rocks.

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Long-continued erosion during the Cretaceous and Tertiary period, coupled with minor oscillations of the land, reduced the Sierra Nevada to a region of low relief, when streams flowed in broad, shallow valleys, in which the earlier auriferous gravels accumulated. Among the finer gravel beds are fossil leaves, including several varieties of figs, oaks, and other plants, which indicate that the flora resembled that of a low coastal country like Florida. Near the low crest volcanic vents poured forth streams of lava, which followed the watercourses, covered the auriferous gravels, and displaced the streams. With this volcanic activity and stream displacement came differential uplift, which greatly increased the stream grades and caused them to cut the deep canyons in which they now flow down the western slope of the Sierra, leaving the auriferous gravels of their old beds on the divides far above.

TOPOGRAPHY.

RELIEF.

As may be seen on the general map of the Honey Lake and Taylorsville regions (Pl. II), the relief consists of two lines of crests and of two valleys, all having a northwest-southeast trend, parallel to the general course of the Sierra Nevada. On the one hand lies the valley of Honey Lake and Susan Creek, and on the other the belt of valleys stretching from Mountain Meadows to Genesee. Between these lines of valleys lies the Diamond Mountain block, whose crest line is prominent from McKesick Peak to Diamond Mountain. The crests of Grizzly Mountains and Keddie Ridge belong to the Grizzly topographic block, and both blocks lie just northeast of the main crest of the Sierra Nevada at its northern end.

DIAMOND MOUNTAIN BLOCK.

The Diamond Mountain block, extending from Honey Lake southwestward to Grizzly Mountains, has a width of over 20 miles and a length north of the fortieth parallel of over 50 miles. Its crest line lies close along its northeastern side, from McKesick Peak to Diamond Mountain, presenting a bold escarpment over 2,000 feet high in the short steep slope to Honey Lake. The slope on the opposite side, to the southwest, is long and gentle, having the appearance of a plateau. Beyond Lone Rock the block gradually narrows, loses its relative elevation, and dies out in a plain before reaching the head of Susan Creek. This disappearance, however, is due more to the general rise of the adjoining county toward Lassen Peak, as shown by the drainage lines, than to any decrease in the general elevation of the Diamond Mountain crest, for it maintains its elevation of 7,000 feet near the end. The prominent features of the Diamond Mountain block are the escarpment, the plateau slope, and the valleys along its western border.

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THE ESCARPMENT.

The escarpment although bold is not generally a cliff, and at two points in a distance of 40 miles between Willow Ranch and Gold Run it is traversed by wagon roads. It is remarkably regular with few prominent spurs and reentrants and gives rise to no considerable stream. Gold Run marks its northern terminus. Beyond that point the eastern slope is as long as the western and the divide becomes symmetrical.

THE PLATEAU SLOPE.

The gentle features of the plateau are best displayed about the heads of Squaw, Last Chance, and Indian creeks, where the general altitude is about 6,000 feet, rising to 7,000 feet at a number of points along the crest. One of the best general views of the plateau is from the slope of Kettle Rock Mountain looking southeast. Although there is a decided community of altitude suggesting an approximation to a common level, it is far from being a complete plain, and yet it may well be called a peneplain. Kettle Rock Mountain is the greatest elevation in it, rising above the general level nearly 2,000 feet, but for the most part by such gentle slopes that the difference of altitude is not out of harmony with the peneplain. The gentle summit slopes continue northwest into Lassen County beyond the limit of the escarpment, where the great difference between the two slopes of the block disappear.

The upper courses of the streams are in broad, shallow valleys, but as they approach the middle portion of the block they cut deeper and deeper until they flow in canyons. Lights Canyon, Cooks Canyon, and the canyons of Indian and Squaw creeks above Flournoy are examples, and they all open into broad alluvial valleys below.

VALLEYS OF THE SOUTHWESTERN BORDER OF THE DIAMOND MOUNTAIN BLOCK.

Genesee Valley.—The general trend of the valley belt along the border of the Diamond Mountain block is northwest and southeast from Genesee Valley to Mountain Meadows. Genesee Valley is at its southeastern extremity. It has a breadth of one-third to three-fourths of a mile, and a length of nearly 6 miles northeast and southwest directly across the general trend of the valley belt. It is a flat alluvial plain on both sides of Indian Creek, with irregular border from jutting spurs and lateral branches running up Red Clover, Wards, Hosselkus, and Little Grizzly creeks. None of it is too swampy for use but some is too dry without irrigation. There is a large ranch at each end and four smaller ones between.

Indian Valley.—Indian Valley is much larger than Genesee, and less regular. The main part extends northwest from Taylorsville to Greenville about 9 miles with an average width of over a mile. At right angles to this is North Arm, which extends up Lights and Cooks

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creeks for nearly 5 miles with a width ranging from a quarter to nearly a mile and widening to the north. Indian Valley proper between Taylorsville and Crescent Mills is nearly all arable, but the adjoining portions of North Arm and Greenville Arm, except the borders, are swampy, although the other portions of both arms have large and excellent farms.

A feature of importance in the main body of the valley 2½ miles northwest of Taylorsville is the Mounds, two dome-shaped hills, which stand out in the valley plain. One rises 100 feet and the other over 200 feet above the surrounding plain. There is a third opposite the entrance of North Arm, a mile north of Taylorsville, but it rises less than 50 feet above the valley plain.

Mountain Meadows.—Mountain Meadows are triangular in shape, widening to the northwest, where they merge into the plains bordering the volcanoes about Lassen Peak. On the southwest they are sharply limited by the steep slopes of Keddie Ridge, but along the eastern side its margin is somewhat less definite on the gentle slope of the Diamond Mountain block. The valley is dry to a large extent except in the northwestern part, which is traversed by Fredonia Creek, from the pass of the same name. Mountain Meadows, having a general elevation of 4,800 feet, is about 1,300 feet above the general level of Indian Valley, from which it is separated by a low divide at the head of Cooks Canyon.

Jura Valley.—Between Mountain Meadows and North Arm of Indian Valley there is a broad gap crossing a flat ridge, and the same is true between North Arm and Genesee Valley, where the gap is a broad depression in the ridge crest that joins Mount Jura to Kettle Rock Mountain. These two gaps belong to the plateau or peneplain features of the Diamond Mountain block. A line joining them lies in the axis of the valley belt, and these gaps are remnants of an old valley along that line nearly 2,000 feet above the present valleys of North Arm and Genesee. This old valley lies on the east slope of Mount Jura, hence the name Jura Valley. It was once occupied by Jura River.

GRIZZLY MOUNTAIN BLOCK.

The Grizzly Mountain block, which lies between the Diamond Mountain block and the main crest of the Sierras and extends from Grizzly Mountains and Keddie Ridge to American Valley, forms only a small part of the Taylorsville region. The Grizzly Mountain block is smaller and much less regular than the Diamond Mountain block.

CREST LINE AND ESCARPMENT.

The crest line and escarpment are well marked in Grizzly Mountains, which present a steep slope of over 3,000 feet to the west end of Genesee Valley. Toward the northwest the crest line sinks and

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curves, running to Taylorsville, where it disappears in the valley, but rises again in Keddie Ridge and curves back to its northwest course. A small notch is cut by Montgomery Creek across the north end of Grizzly Mountains, but the broad gap in the crest occupied by Indian Valley is more than a mile in width. Keddie Ridge, which carries the crest beyond Indian Valley, is about 14 miles in length and ends in plains at both extremities.

SOUTHWEST SLOPE.

The southwest slope of Grizzly Mountains is larger and gentler than the slope in the opposite direction, but is not so gentle as the corresponding slope of the Diamond Mountain block and retains but few, if any, definite traces of an inclined peneplain. South of the fortieth parallel the crest continues for 15 miles to Grizzly Peak, and a parallel valley follows the western edge of the block all the way from Mohawk to American Valley. About Crescent Mills and Greenville the western slope is broken down to the level of Indian Valley, which crosses the main crest, giving especial prominence to the escarpment of Arlington Heights and Houghs Peak, which form a second crest. Beyond Round Valley Reservoir the slope of the Grizzly Mountain block is better preserved in the northwestern inclination of the divide between Indian Creek and North Fork of Feather River.

DRAINAGE.

The Taylorsville region belongs to two drainage systems, the Great Basin and the Sacramento River, and the water parting is along the eastern crest of the Diamond Mountain block. That which belongs to the Great Basin finds its way into Susan Creek or upper Long Valley, and finally into Honey Lake, which has no outlet, and lies at the very base of the Diamond Mountain escarpment, receiving nearly all its water from the streams flowing southeast or northwest parallel to the escarpment.

All the drainage west of the Diamond Mountain crest goes into the North Fork of Feather River. The drainage from Mountain Meadows passes around the northern end of Keddie Ridge of the Grizzly Mountain block into Big Meadows, where it enters North Fork of Feather River.

The part of the Diamond Mountain block within Plumas County is drained by Indian Creek, whose branches from Cooks Canyon to Last Chance Creek, inclusive, head along the crest forming the county line, while Squaw Creek drains Red Clover Valley, which heads against the great Sierra Valley. The Diamond Mountain and Grizzly blocks, which combine south of the fortieth parallel and merge into the broad summit, Sierra Valley, are completely drained by the tributaries of Feather River. North Fork drains all that part lying north of the fortieth parallel in the Taylorsville region except a small

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System.
Quaternary
Tertiary
Early Cretaceous & late Jurassic.
Jurassic
Triassic
Carboniferous
Devonian ?
Silurian

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area along the crest 3 miles south of McKesick Peak, which is drained by Sierra Valley into the Middle Fork of Feather River. Both forks of Feather River have cut profound canyons across the crest of the main Sierra block on their way to the Sacramento.

As regards the grades of drainage lines in the Taylorsville region, it should be noted that the headwaters tributary to Indian Creek, being on the peneplain, have exceptionally low grade. From the peneplain the streams pass with steep grades through canyons to Indian Valley, upon leaving which Indian Creek again enters a deep, rugged canyon to Feather River.

DESCRIPTIVE GEOLOGY.

GENERAL STATEMENT.

The results of the areal survey of the Taylorsville region are expressed upon the geologic maps, Pls. II and III, in the discrimination of 18 sedimentary and 12 igneous formations. These contrasted formations are of about equal volume in the district represented by the Indian Valley special sheet (Pl. III), but in the surrounding district upon the north and east, as shown in Pl. II, igneous rocks prevail everywhere, though they are locally covered by auriferous gravels or Quaternary lake deposits.

SEDIMENTARY ROCKS.

GENERAL ACCOUNT.

The sedimentary rocks of the Taylorsville region contain a more nearly complete record of the geologic history of the Sierra Nevada than has yet been reported in any other portion of the range. The Silurian and Devonian are each represented by 1 formation, but 4 occur in the Carboniferous, 2 in the Triassic, 7 in the Jurassic, 1 in the Tertiary, and 2 in the Quaternary.

The Grizzly formation is the oldest. It is mainly quartzite with some shale, and at the top are occasional lentils of limestone. Its fossils are clearly of Silurian age. The Devonian slates and quartzites, with local basal conglomerates, have not yet yielded any fossils, but the Carboniferous, represented by the Arlington, Shoo Fly, Peale, and Robinson formations, have fossils at various horizons. These are followed by the Swearinger slate and Hosselkus limestone, whose rich Triassic fauna has long been known. The Jurassic strata, beginning with the Trail formation, continues in succession with the Hardgrave sandstone, Thompson limestone, Mormon sandstone, Bicknell sandstone, Hinchman sandstone, and Foreman formation, most of the horizons being characterized by abundant faunas. The latest Jurassic and Cretaceous are not represented in the Taylorsville region. The auriferous gravels of Tertiary age complete the column to the Quaternary. (See Pl. IV.)

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SILURIAN.

GRIZZLY FORMATION.

Lithologic character.—The Grizzly formation is a gray, well-defined but thin-bedded quartzite overlain by lentils of limestone and interstratified with shaly; often siliceous slate (argillite) having irregular cleavage. The beds of quartzite range from 5 to about 20 feet in thickness and run out into shale in a short distance. The shale beds are generally thicker than the quartzite. They are for the most part greenish gray to drab, but sometimes black and more or less flinty, but not much altered. The lighter colored shales are often sandy and constitute the prevailing portion of the formation, although beds of well-marked quartzite are usually present and frequently predominate. The coarser beds of quartzite contain small pebbles of rhyolite, rarely as large as a pea. These beds, with occasional little pebbles, are near the base of the formation and have a thickness of about 200 feet. The black shale, sometimes flinty, is full of traces of organisms, which E. O. Ulrich has identified as sponge spicules. On the eastern slope of Grizzly Mountains, near the northern end, quartzite prevails immediately beneath a lentil of limestone, but north of Montgomery Creek shales occupy the corresponding position, as shown in fig. 2. The section as shown in this figure, however, does not continue below the tunnel, and therefore does not disclose the coarser beds lying at the bottom of the Grizzly quartzite horizon.

Areal distribution and thickness.—The quartzite of the Grizzly formation occupies a narrow belt near the crest and parallel to it on the northeast slope of Grizzly Mountains. It extends from Taylorsville southeast across Montgomery Creek and along the slope, where it is cut into patches by pyroxenite and meta-andesite, reaching the fortieth parallel in the glaciated ravine half a mile northeast of Tower Rock. At this point the belt of Grizzly quartzite abruptly narrows and vanishes along the border of the ancient rhyolite and the overlapping basaltic volcanics. Immediately south of the fortieth parallel this rock has been sought for by H. W. Turner in the Downieville quadrangle, but its presence could not be demonstrated. The length of the belt of Grizzly quartzite from Taylorsville to the fortieth parallel is about 6 miles, and its exposure is not known to extend beyond in either direction. A portion of the area mapped as Grizzly formation about the mouth of Montgomery Creek, embracing a tract one-fourth of a mile in width and nearly 2½ miles in length along the left bank of Indian Creek, is referred to this horizon with doubt. Although quartzite and siliceous slates occur there the prevailing rock is thin-bedded sandstone instead of quartzite. Locally the sandstone contains pebbles, but it is generally fine

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grained. At one point it shows decided spheroidal weathering and resembles certain beds in the Arlington formation, from which, however, it differs decidedly in mineral composition. The spheroidal sandstone in question near Montgomery Creek contains quartz grains whose bipyramidal form indicates that they were most likely derived from the underlying metarhyolite.

There are two small outliers of the Grizzly formation near the fortieth parallel a mile northeast of Tower Rock. In both cases they are masses of much crumpled black, flinty slates from 25 to 40 feet in thickness associated with the ancient rhyolite into which they have been folded or faulted.

The thickness of the Grizzly formation, where measured near the northern end of Grizzly Mountains, is about 400 feet, and this is near the maximum. The strike of the formation is northwest and southeast parallel to its outcrop, and its dip is southwest into Grizzly Mountains between Taylorsville slates which lie upon it and a mass of ancient rhyolite on which it rests.

Relation to adjoining formations.—The contact of the Grizzly formation and the underlying rhyolite is more or less irregular and difficult to follow, but the irregularities are those of the original lava surface accented by much subsequent folding and displacement. This relation may be plainly seen on the lower slope of Grizzly Mountains opposite Huntingtons, where a tongue of sandstone is folded into the metarhyolite, whose fluidal structure on both sides is parallel to the well-marked bedding in the sandstone. That the rhyolite is older than the overlying quartzite is evidenced by the fact that small pebbles of the rhyolite occur in the quartzite. Although not abundant nor large they are common and characteristic, and confirm the view that the quartzite was deposited on the rhyolite.

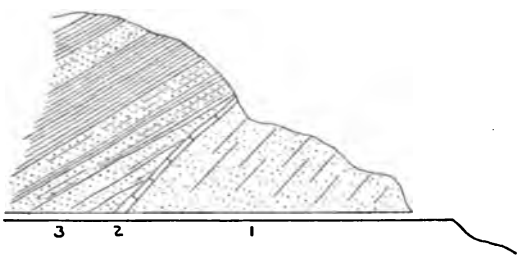

FIG. 2.—Tunnel section of Grizzly formation (1), Montgomery limestone (2), and Taylorsville formation (3).

Above the quartzite comes the Montgomery limestone, and the two are conformable, as shown in the small section (fig. 2) along the tunnel on the east slope near the crest of the ridge 2 miles south of Taylorsville. The fine conglomerates, sandstones, and slates of the Taylorsville formation overlie the limestone and quartzite apparently with unconformity.

Fossils and age.—The only fossils discovered in the Grizzly formation, outside of the limestone lentils, are sponge spicules found in thin sections of the black shaly portions. They indicate a marine origin

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for the sediments, but afford no definite information as to its age. There can be no reasonable doubt, however, that it is older than the lentils of limestone described below.

MONTGOMERY LIMESTONE.

Lithologic character.—This limestone was called the Montgomery[a] limestone from its occurrence on that creek, 2½ miles south of Taylorsville. The limestone is light to dark bluish gray and cleaves into plates. It has occasional knots or benches of black chert and some of the few fossils are replaced by it. The form of the limestone is lenticular, and the largest lentil has a thickness of 60 feet, with a length of about 200 feet. The strike is approximately parallel to the crest of Grizzly Mountains, and the dip is to the southwest.

Areal distribution.—Five of these limestone lentils have been found at intervals along the western border of the quartzite between Taylorsville and the fortieth parallel. The first occurs at the tunnel shown in fig. 2, where it has a thickness of 20 feet. The second is on the south bank of Montgomery Creek, forming prominent cliffs at an altitude of about 4,000 feet. The third and largest lentil, 60 feet in thickness, is on the crest of Grizzly Mountains, at their northern end, having an altitude of nearly 7,000 feet. This is by far the most important lentil, on account of the fossils it contains. Two miles farther southeast, in the cliff overlooking the Devils Punch Bowl, is a lentil of limestone about 15 feet in thickness and exposed for 60 feet. No fossils were found here, but the limestone is in the same horizon as that containing the fossils at the northern end of Grizzly Mountains. The last and smallest lens of limestone occurs in the slates near the top of a flat spur one-eighth of a mile north of the fortieth parallel. It is only about 4 inches in diameter. South of the fortieth parallel Turner has not been able to find any exposed lentils of the limestone, nor have any been found by the writer north of Taylorsville. Limestone has been reported from a well on one of the mounds of Indian Valley, but the determination is a matter of doubt. The extreme limits of the exposed lenses are about 12 miles apart.

Fossils and age.—Fossils were discovered in this limestone on Montgomery Creek and the crest of Grizzly Mountains by Cooper Curtice in 1890. A few fossils were added by others to those collected by Curtice, and among them C. D. Walcott identified the following forms:

Crinoid stems.	Heliolites.
Stromatopora sp. (?).	Halysites catenulatus.
Zaphrentis.	Orthis (of the type of O. flabellum).
Syringopora (like S. serpens).	Ormoceras (cf. siphuncles).

[a] Bull. Geol. Soc. America, vol. 3, 1892, pp. 372 and 376.

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According to Walcott, these fossils are undoubtedly Silurian and "represent the Niagara horizon of the Mississippi Valley and Appalachian provinces."

Last summer the locality was visited and a collection made by James Storrs. It was referred to E. O. Ulrich, who reports as follows:

The fossils on the whole are in very discouraging condition and in most cases it is impossible to determine them specifically.

1. Halysites catenulatus. The variety that is found, so far as known to me, only in the Silurian above the Clinton.
2. Heliolites cf. interstinctus.
3. Heliolites cf. elegans.
4. ? Favosites. A small ramose species.
5. Cyathophyllum sp. undet. A small, subcylindrical species.
6. Fragment of a single tube of an undetermined species of Syringopora.

The above fossils are all corals of types indicating an early middle Silurian—in other words, about the age of the Louisville Niagara limestone.

No other exposures of fossiliferous rocks of this horizon are known within hundreds of miles. One of the nearest is in the Eureka region of central Nevada.

Relation to adjacent formations.—In strike and dip the limestone and the underlying quartzite are practically parallel, and their observed contacts indicate conformability. The change in the character of the sediment from siliceous sand and clay to local limestones may have been due to subsidence of the sea floor, but it did not involve deformation sufficiently great to give rise to discordance between the strata. But at about the horizon of the top of the limestone the change in sediments, which become at least locally coarse, appears to be consequent upon deformation of a more pronounced character and will be noted more fully under the Taylorsville formation.

DEVONIAN.

TAYLORSVILLE FORMATION.

Lithologic character.—The Taylorsville formation is composed for the most part of fine sediments, chiefly slates[a] and thin-bedded sandstones, among which there are numerous small layers of fine black chert or occasional less regular masses of red chert, but at the base it is locally a fine conglomerate, and near the middle there are well-defined beds of light-colored quartzite. The conglomerate at the base is greenish gray and its pebbles are indistinct. It is best exposed on the eastern face of the spur above the limestone about a mile south of Taylorsville. The pebbles are small and, in part at least, well rounded. Many of them are of igneous material more or less por-

[a] The Taylorsville formation was formerly called the Taylorsville slates; Bull. Geol. Soc. America, vol. 3, 1892, p. 372.

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phyritic. Some are rhyolitic, and in places small fragments of chert are common containing the round spots like those of the siliceous slates in the Grizzly quartzite. Thin sections of the ancient rhyolite show its groundmass very like that of some of the chert. They are easily distinguished in some cases by the presence of quartz phenocrysts on the one hand or round spots of organic origin in the other.

Distribution and thickness.—The Taylorsville formation is best developed a short distance south of Taylorsville, and except where cut by serpentine and pyroxenite it forms a belt southeast along the slope of Grizzly Mountains to the fortieth parallel. Like the Grizzly formation, the exposure of the Taylorsville formation ends near the fortieth parallel. Neither of them has been recognized by Turner in the Downieville quadrangle, which lies immediately south of the fortieth parallel.

Northwest of Taylorsville the outcrop of the Taylorsville formation is interrupted by alluvial deposits of Indian Valley, and it appears beyond only in isolated areas on the end of Keddie Ridge and on the Mounds, and also 2 miles north of Crescent Mills and 1½ miles west of Greenville. The last is the largest of the isolated areas and contains besides quartzite and shales some distinctly banded black cherts, in which there are no traces of organic remains. West of this area there is a small exposure in the Lassen Peak quadrangle, a few miles east of Prattville on the border of the great lava field. It is probable that some of the isolated areas mapped as Taylorsville formation north and northwest of Indian Valley contain strata which belong to the Grizzly quartzite, but in the absence of the Montgomery limestone they could not be separated.

The known extent of the Taylorsville formation is about 35 miles. For 12 miles northwest of Tower Rock on the fortieth parallel it is associated with the Grizzly formation, but beyond Taylorsville it extends alone with numerous interruptions for about 20 miles to its final cover of lava in the Lassen Peak region. The general dip of the formation throughout its extent, where not disturbed by igneous intrusions, is to the southwest.

The thickness of the Taylorsville formation in the measured section 1½ miles south of Taylorsville is about 1,800 feet. From this point it appears to thin southward. Near the fortieth parallel only 150 feet are exposed. North of Taylorsville it is so involved with igneous rocks that its thickness has not been determined, but if width of exposure may be taken as an indication the thickness increases in that direction.

Relation to adjacent formations.—The fossiliferous cherty shale pebbles in the conglomerate at the base of the Taylorsville formation appear to have been derived from the black shales of the Grizzly formation and indicate an unconformity of erosion between them,

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although the rocks upon both sides of the contact have essentially the same position. The lack of continuity in the Montgomery limestone suggests that the unconformity is between the limestone and the Taylorsville formation, and while this is probable it could not be fully confirmed. No pebbles of limestone were found in the conglomerate and the masses of limestone do not appear as irregular remnants left by erosion from a larger mass but are lenticular in shape, as if originally so formed.

Evidence upon this point also may be observed north and northwest of Indian Valley, where the Taylorsville formation appears to lie directly upon the quartz porphyry. The quartzite and limestone of the Grizzly formation were apparently removed by erosion from the surface of the metarhyolite before the deposition of the Taylorsville formation. The local conglomerate, associated with flinty slates and gray sandstones of the Taylorsville formation, was observed in the long, narrow strip running along the western slope of Keddie Ridge parallel to its crest. The pebbles are largely of igneous material, chiefly acid volcanics, presumably derived directly from the adjacent quartz porphyry, which the fragments closely resemble. On the whole, therefore, the evidence seems to indicate a decided unconformity of erosion between the limestone and the Taylorsville formation.

On the upper side—that is, on the southwest—the Taylorsville formation is limited by igneous rocks only. Taylor meta-andesite, a basic volcanic rock which spreads from the vicinity of Taylor Rock, overlies the Taylorsville formation on the western slope of Grizzly Mountains, but farther northwest, along Houghs Creek, granite separates it from the Arlington formation.

Age.—The only fossils found in the Taylorsville formation are sponge spicules in the cherty shales, and they are not distinctive. It is certainly younger than the Silurian, which it unconformably overlies. The abundance of the black chert layers is significant on account of the fact that the Devonian strata of the Redding quadrangle of Shasta County, about 100 miles to the northwest, are especially cherty, and in this respect contrasted with the overlying formations of Carboniferous age. In the Taylorsville region the next horizon of sediments above the Taylorsville formation is the Arlington, which is free from chert and is probably of Carboniferous age. The abundance of Devonian sediments in the Redding quadrangle leads one to expect them at this horizon in the Taylorsville region, whose general section has many features in common with that of Shasta County, and it is probable therefore that the Taylorsville formation is Devonian in age.

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CARBONIFEROUS.

CALAVERAS GROUP.

The Calaveras group was named by Becker, Lindgren, and Turner in their survey of the Gold Belt to include a great body of more or less altered sandstones, shales, and limestones of Carboniferous age. It is widely distributed and occupies a greater area than any other sedimentary formation in the Sierra Nevada. Turner has mapped the Calaveras in the Downieville quadrangle, from which it extends directly across the fortieth parallel into the Taylorsville region.

In order to emphasize the essential unity of this succession of sediments in the Taylorsville region we continue to use the term Calaveras for all those sediments connecting directly with the Calaveras of the Downieville quadrangle. But to bring out the areal distribution and possibly also slight differences in age of the various parts of the Calaveras in the Taylorsville region, it is subdivided, largely as heretofore,[a] into the Arlington formation, the Shoo Fly formation, and the Peale formation, which will be considered separately before the latest Carboniferous, the Robinson formation, is taken up.

ARLINGTON FORMATION.

Lithologic character.—The Arlington formation is made up chiefly of fine, gray, thin-bedded sandstone, with some shale in part silicified and a few beds of conglomerate. It may be considered as having three members. In the lower member yellowish shales prevail, grading upward into shaly and thin-bedded greenish-gray sandstone, of which a great mass constituting the middle member is exceptionally well exposed in the bold escarpment of Arlington Heights. There is a narrow belt of yellowish-gray sandstone in the upper portion of the middle member that is somewhat coarser than the rest and is characterized by well-developed spheroidal weathering. It is composed of angular grains of fresh plagioclase, with a smaller amount of augite, green hornblende, and magnetite. Quartz, if present at all, is not common. This peculiar sandstone bears considerable resemblance to certain tuffaceous beds found in the Bragdon formation of the Redding quadrangle of California, but in the present case no definite volcanic material could be recognized either in the field or under the microscope to prove its volcanic origin.

In the upper member slaty gray shales are most abundant, with local conglomerates and highly silicified red jaspery portions near the top. The slaty shales are well exposed about Crystal Lake, where they occasionally split into thin slabs several feet in diameter. In the summit of Houghs Peak the silicification is extreme, and the mass is converted into red and gray chert veined with white quartz associated with small veins of magnetite and staining of hematite.

[a] Geology of Taylorsville region: Bull. Geol. Soc. America, vol. 3, 1892, p. 372.

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In the cliffs along the western border of Crystal Lake are beds of conglomerate interstratified with the slaty shale in which a few fossils have been found. Most of the pebbles are of gray chert, but a few are of red chert and sandstone, and locally there are a considerable number of pebbles of a holocrystalline, hypautomorphic granular igneous rock composed largely of feldspar with less chlorite and small amounts of magnetite and quartz. The chlorite probably represents original augite. The feldspar is sometimes (as in 6696) untwinned. When twinned (as in 6699) they appear to be Carlsbad showing only two bands. Rarely smaller bands appear, but evident polysynthetic twinning is certainly not present. The pebbles of igneous material are well rounded, waterworn, and very largely of the type noted above, which for the present may be called quartz-augite diorite.

The interbedded slates and conglomerates strike N. 36° W. and dip 54° SW., and the well-marked slaty cleavage is parallel to the stratification. The conglomerate is not coarse. Its largest pebbles are rarely over 4 inches through, but they have all suffered decided deformation, which reached a maximum in the plane of cleavage. The rock is cut by two systems of joints; one runs N. 40° E. and dips 69° SE., while the other strikes N. 36° W. and dips 45° NE.

FIG. 3.—Side-fractured pebble in conglomerate of Crystal Lake.

Joints of both systems cut directly through the pebbles. On the first system the pebbles have been greatly elongated; on the second system the same pebbles are but slightly drawn out, and the greatest deformation in both cases lies in the plane of cleavage. Some pebbles are embedded in the slates and there often fractured, as shown in fig. 3 from a photograph illustrating pebbles exposed on a joint of the northeast-southwest system. The degrees of fracturing range from incipient cracks on the upper side only to complete fissuring and faulting, as illustrated in fig. 4, as if the upper part of the pebbles was in a plane of greater motion than the lower, resulting in the upper-side fracturing of many pebbles and the faulting of a few having the imbricated faulted parts inclined in the same direction as the slaty cleavage.

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Distribution and thickness.—The Arlington formation has its greatest development between the summits of Houghs Peak and Houghs Creek. From this point it extends northwest into the Lassen Peak quadrangle and has been briefly described in the folio of that quadrangle. To the southeast it extends with diminishing width of outcrop to a short distance beyond the fortieth parallel into the Downieville quadrangle, where it is entirely cut off by the volcanic mass of meta-andesite ("augite porphyrite") from the vicinity of Taylor Rock. The total length of the outcrop is about 30 miles. The stratification is clearly marked with strike northwest and southeast and dip to the southwest, and with a regularity that indicates conformability throughout the entire succession of strata having a measured thickness of 5,700 feet.

Relation to adjoining formations.—The Arlington formation on the surface is completely surrounded by igneous rocks. About the southeast end and on the south and southwest the formation is limited by a great volcanic mass of meta-andesite. On the northeast it is limited by metarhyolite and serpentine in the Greenville region, but along Houghs Creek it is bounded by granodiorite. All of these bordering igneous rocks except the metarhyolite are younger than the Arlington formation and penetrate or overflow it. They separate the Arlington beds on the one hand from the Taylorsville formation and on the other from the Shoo Fly beds of the Calaveras. In general position the Arlington formation is parallel to both of these formations and lies between them.

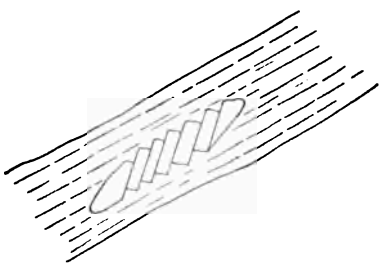

FIG. 4.—Faulted pebble in slaty conglomerate of Crystal Lake.

Fossils and age.—The only fossils found in this formation were discovered by James Storrs on the border of Crystal Lake. Girty reports from this locality "crinoid stems, coral?, *Stenopora?* sp.," and remarks that it "is probably Paleozoic, but possibly not Carboniferous." It is younger than the Taylorsville and older than the Shoo Fly portion of the Calaveras. One is probably Devonian and the other apparently Carboniferous, so that the probable age of the Arlington is either late Devonian or early Carboniferous. In the Redding region there is a great thickness of early Carboniferous sediments in the Baird and also in the Bragdon, which is poor in fossils below and in some respects, as already pointed out, like the Arlington. It is possible that the Arlington and Bragdon represent approximately the same horizon of Carboniferous below the great limestones of that system.

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SHOO FLY FORMATION.

Lithologic character.—The Shoo Fly formation[a] was named from a locality on the stage road between Crescent Mills and Quincy, near the bridge crossing Indian Creek, where the beds are well exposed. They consist mainly of clay slates above and quartzite below. The clay slates are light to dark gray, generally dull, but sometimes silky and in places slightly micaceous. They contain occasional films of gray or black flinty material, as well as thin beds of sandstone and fine conglomerate of quartz pebbles, leaving no doubt as to the sedimentary origin of the formation, and yet one finds traces here and there of beds composed exclusively of volcanic fragments, some of which are clearly vesicular. Near the middle portion are lentils of limestone, some of which attain a thickness of over 50 feet and form conspicuous ledges on the spur half a mile east of Clear Creek Bridge.

The quartzites which prevail in the upper portion of the formation are thin bedded, somewhat slaty, and indistinctly schistose with micaceous partings. On a fresh fracture the quartz grains are bluish, but the rock weathers reddish. Veins of white quartz are common and locally abundant throughout the formation, and in general it may be said that the Shoo Fly beds are more affected by regional metamorphism than any other strata in the Taylorsville region.

Areal distribution and thickness.—The Shoo Fly formation occupies the southwest corner of the Taylorsville region and is well exposed on the road between Shoo Fly Bridge and Spanish Creek. This is part of the large area to the west and south around American Valley as illustrated by the areal map in the Downieville folio by Turner.

The development of cleavage in the Shoo Fly formation has obscured its stratification and rendered the determination of its thickness more difficult. A measured section makes it 6,800 feet thick, but this is probably too high.

Relation to adjacent formations.—The Shoo Fly formation is everywhere separated from the Arlington by a wide belt of meta-andesite of volcanic origin, indicating that the epochs during which the two sets of beds were deposited were separated by an interval of contemporaneous volcanic activity. The general dip of both sets of strata is to the northwest, and there can scarcely be any doubt that the Shoo Fly formation overlies the Arlington and is of later deposition.

Age.—Traces of crinoids were the only fossils found in the Shoo Fly formation of the Taylorsville region, but a few miles to the southwest, near Spanish Ranch, occur characteristic Carboniferous fossils, such as *Fusulina*, leaving no doubt as to the age of that portion of the Calaveras group.

[a] Bull. Geol. Soc. America, vol. 3, 1892, pp. 272-275. In the Lassen Peak folio they were included in the Calaveras.

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PEALE FORMATION.

Lithologic character.—In lithologic character the Peale formation is decidedly variable. Reddish to brown slaty shale, sometimes gray or greenish, passing into tuffaceous sandstone and fine conglomerate, is most common. The fine conglomerate contains much volcanic material, with occasional red lapilli and small lenses of calcareous matter. Thin beds of gray quartzite occur also, and masses of black, gray, or red chert form prominent ledges.

The tuffaceous beds are well exposed and fossiliferous on the horse trail from Wards Creek to Peale diggings, also beyond Hosselkus and to within about a mile of the Lucky S road. The chert is best exposed near the forks of the road just east of Hosselkus, where there is a prominent ledge of red banded chert full of quartz veins, but no considerable amount of hematite with it as on Houghs Peak. Red siliceous slate and chert occur near the summit along the trail from Wards Creek to Peale diggings, as well as in the divide at the head of Hinchman Ravine, but the locality for most conspicuous banding, like that of the Marquette iron-ore region of Michigan, is a mile northwest of Evans Peak and still farther in the same direction near Keddie Lake. At the last two localities, which lie beyond the limits of the Indian Valley Special sheet, the Peale beds have not been separated from the Robinson formation.

Areal distribution and thickness.—The Peale formation makes a narrow interrupted belt extending from Little Grizzly Creek north across the fortieth parallel at Peale diggings, on the divide between Wards Creek and Little Grizzly Creek, then somewhat more westerly across Genesee Valley at Hosselkus to the divide 2 miles northeast of Mount Jura, where it is covered up by the overlapping Foreman formation before reaching the Lucky S road. Small masses of these beds, chiefly red chert, adjoin the gravel of the Taylor diggings and form much of the hill at the head of Hinchman Ravine. In Keddie Ridge, northwest of Evans Peak, masses of chert occur, and they probably belong to the horizon of the Peale formation, but were not separated from the Robinson, which occurs in the same region. The thickness of the Peale formation, measured 2 miles east of the summit of Mount Jura, is about 1,400 feet.

Fossils and age.—Fossils were discovered in the Peale formation by T. W. Stanton along the trail to the Peale diggings at an elevation from 4,500 to 5,000 feet. Several collections were made by others at the same place in 1893, and all the collections were examined by Charles Schuchert, who reports the following:

Orthis michelini.
Streptorhynchus crenistria?
Amboccelia planiconvexa.
Spirifer striatus.
Productus? sp.
Pelecypod like Yoldia or Leda.
Phillipsia sp.
Lophophyllum profundum.

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In 1904 Storrs and I collected a number of fossils near the same place. They were examined by G. H. Girty, who reports (January 12, 1905) the following forms:

Fusulina sp.	Meekopora sp.
Crinoid fragments.	Stenopora? sp.
Fistulipora sp.	

Girty states (May 18, 1905):

I have also examined the collection upon which Mr. Schuchert reported. The fauna is well shown by Mr. Schuchert's list, and I regret to say seems to possess little in common with the fossils from the same area reported on January 12, 1905, which I examined, and also with those from the Robinson beds. In fact, if this fauna be brought into comparison with those of the McCloud River section, it is more nearly related to the Baird fauna than to those of the McCloud limestone or Nosoni formation. At the same time I am not prepared to definitely correlate the material examined by Mr. Schuchert with the Baird, as many of the characteristic Baird species are wanting.

There seems to be no doubt that the Peale formation is Carboniferous, and most likely older than the Robinson formation, to be noted presently. In the Downieville folio the Peale formation, which extends south of the fortieth parallel, was included by W. H. Turner in the Calaveras formation, and in the Genesee Valley region there is not sufficient reason for their separation.

The chert near Hosselkus is minutely spotted as if radiolarian. In thin section the microscope reveals the fact that the chert contains many spots with sufficient structure to enable Ulrich to determine their radiolarian origin. No trace of sponge spicules, such as are so common in the cherts of the Grizzly and Taylorsville formations, was found.

Relation to adjacent formations.—The Peale formation is almost completely surrounded by igneous rocks, meta-andesites, and is in part made up of pyroclastic material of the same sort. It is evident, therefore, that it represents approximately an epoch of volcanic activity, although the rock by which it is immediately enveloped may be in large part intrusive. This appears, at least, to be the case of the mass which splits the belt of the Peale formation into two parts southeast of Genesee.

The Peale formation dips to the southwest and overlies the meta-andesite which separates it from the Robinson formation on the northeast, but, as will be explained in considering the Robinson formation, the rocks have been overturned. Farther northwest, in the head of South Fork of Foremans Ravine, the outcrops of jaspery and associated rocks cease, and the Peale formation appears to run under the Foreman formation, by which it is unconformably overlapped. No fossils were found in that vicinity and the contact was not definitely traced.

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ROBINSON FORMATION.

Lithologic character.—The Robinson formation includes a succession of variable sediments ranging from shale to conglomerate and composed chiefly of igneous material with occasional lentils of limestone. The most characteristic portion is a gray sandstone which weathers reddish brown. It contains more or less disseminated carbonates of lime forming small lentils up to 15 feet in thickness. Microscopic examination shows that the sand of which it is composed is largely of volcanic material, and includes traces of crinoids, with occasional bryozoa in many cases, even when they can not be seen with the unaided eye. Below the calcareous horizon the reddish-brown thin-bedded tuffaceous sandstone and shale extend to the bottom of the formation. Above that horizon the pyroclastic material becomes somewhat coarser and passes into a tuffaceous conglomerate containing fossiliferous limestone nodules and beds of reddish-brown sandstone, here and there with crinoid stems like that of the principal horizon below. Crystals of feldspar are common and sometimes prominent in this tuffaceous rock, giving it the general aspect of a solid lava flow, and there is good reason for surprise on finding in it distinct impressions of gasteropods, spirifers, corals, and crinoids.

Areal distribution and thickness.—The Robinson formation forms a subdivided and greatly interrupted belt, extending from 4 miles south of the fortieth parallel on Little Grizzly Creek northwest across Genesee Valley and the Lucky S mine road divide, and disappears before reaching North Arm of Indian Valley. Beyond Evans Peak it reappears, extending along the slope of Keddie Ridge, as shown in Pl. V, to its northern end, beyond Dyer Peak, where it sinks beneath the lavas of Lassen Peak. The width of the belt is from one-half to 1½ miles, and the total length is nearly 30 miles.

The belt is divided longitudinally by volcanic rocks into two subordinate belts, which cross Genesee Valley at the ranch known as Robinson's, from which the formation is named. On the north side of Genesee Valley the rocks of this formation make up the mound east of the Robinson house and the point crossed by the road west of the house. At the last locality the brown calcareous sandstones and tuffs are full of fossils. The outcrop passes between the two ledges of the Hosselkus limestone and follows the western border of that limestone northwest beyond Hosselkus Creek. It is cut off by meta-andesite along the summit of the divide, but reappears and shortly ends on the north side in a ravine leading down to Peters Creek. Several miles farther northeast on Peters Creek, running up from the trail at an altitude of about 4,500 feet, there is a small mass of characteristic reddish and gray tuffaceous sandstone enveloped by igneous rocks. The characteristic little fossils it contains leave no doubt as to its identity. Similar sandstones were found at other

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points along Peters Creek, but thin sections revealed no microscopic fossils. Isolated outcrops of Robinson beds occur also near the fortieth parallel among the tributaries of Wards Creek.

The thickness of the Robinson formation measured a short distance north of Genesee Valley is 1,150 feet. At that point the structure is complex and the exposure not complete, but the total thickness can not be much greater.

Fossils and age.—The first fossils collected from the Robinson formation were probably obtained by Ashburner, Brewer, and King in 1861, but sufficient characteristic fossils to determine the horizon were not obtained until 1890, when Cooper Curtice visited the region and discovered many new localities of Mesozoic and Paleozoic fossils. Since then a large number of fossils have been collected at various points from the Robinson formation, chiefly from the reddish-brown sandstone and tuff on the first spur, about half a mile northwest of the Robinson house.

December 8, 1891, C. D. Walcott reported the following fossils from the Robinson locality:

Campophyllum ? sp.
Favosites sp.
Crinoids.
Archæocidaris.
Fenestella 2 sp. undet.
Streptorhynchus crenistria.
Productus semireticulatus.
Productus punctatus ?
Spirifer lineatus?
Spirifer cameratus.
Rhynchonella sp.
Meekella like striaticostata Cox.
Aviculipecten 2 sp.
Aviculipecten interlineatus.
Myalina of subquadrata type.
Edmondia sp.
Pleurotomaria sp.

From essentially the same locality Storrs, in 1904, collected fossils numbered 6885 and 6886, among which Girty identified:

Calcareous algæ?
Fusulina elongata Shum.
Lophophyllum n. sp.
Squamularia near S. guadalupensis.
Dielasma ? sp.
Actinostroma ?? sp.
Stromatopora ?? sp.

Half a mile northwest of the Robinson locality, on the west of the ridge, at an altitude of 4,700 feet, in approximately the same beds, more fossils were collected (No. 6749), among which Girty (January 12, 1905) recognized:

Calcareous algæ?
Fusulina sp.
Rugose coral ?
Archæocidaris sp.
Rhombopora, lepidodendroides group.
Spirifer sp.
Squamularia cf. S. guadalupensis.
Spiriferina n. sp.
Aviculipecten sp.
Pseudomonotis ? sp.
Myoconcha ? sp.
Indeterminable forms.

In the collections from the conglomerate (6732–6734) between the two localities noted above Girty found:

Aulopora sp.
Striatopora n. sp.
Cystodictya sp.
Rhombopora, type of lepidodendroides.
Lophophyllum ? sp.
Streptorhynchoid brachiopod ?

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Some of the fossiliferous limestone nodules in the conglomerate looked like pebbles, but their occurrence in fine beds interstratified with the conglomerate shows that the calcareous nodules are indigenous and not derived. The above lists, as far as I am aware, contain the only fossils thus far determined from the type locality of the Robinson formation on the north side of Genesee Valley.

South of Genesee Valley, near the Five Bear mine on the west side of Wards Creek, G. H. Goodhue found in the Robinson belt some imperfect fossils among which Girty recognizes the "dorsal valve of a brachiopod belonging to the genus *Meekella*, though possibly it might be a *Geyerella*." This locality is just west of the mill of the Five Bear mine, and the material looks promising for the collector.

Four miles south of the fortieth parallel, on Little Grizzly Creek, at the southern end of the Robinson belt as mapped by H. W. Turner in the Downieville folio, a number of fossils were collected at various times by Curtice and Stanton. Girty has recently examined the collections and reported the following forms:

Crinoid stems.
Archæocidaris sp.
Crania sp.
Schizophoria sp.
Orthotetes ? sp.
Meekella sp.
Chonetes n. sp.
Productus semireticulatus ?
Marginifera n. sp.
Spirifer aff. S. cameratus.
Spirifer sp.
Spiriferina aff. S. pulchra.
Squamularia lineata ?
Pugnax ? sp.
Rhynchonella sp.
Myalina sp.

Since the Robinson formation was named [a] the extensive development of the Carboniferous in the McCloud River region of California has been studied and subdivided into Nosoni, McCloud, Baird, and Bragdon. The Genesee and McCloud localities are over 100 miles apart, and from a paleontological point of view Girty has given the following statement concerning their correlations:

> The fauna of the Robinson beds is varied and interesting, although always preserved so as to make its study a difficult matter. Comparing it with the three well-characterized faunas of the McCloud River section, those of the Baird, McCloud, and Nosoni formations, one readily discovers a rather close correspondence to the Nosoni fauna, while nothing resembling the faunas of the Baird and McCloud formations has yet been found in the Robinson beds. As many species are common to the two formations, the evidence at hand certainly favors correlating the Robinson with the Nosoni.
>
> The fauna from Little Grizzly Creek, while showing certain differences from the typical Robinson, probably belongs to the same horizon. It is at least not the fauna of the Baird or McCloud.

In the foregoing lists of Girty "calcareous algæ" refers to a very minute, almost microscopic, fossil first discovered in the Carboniferous limestone of the Klamath Mountains.[b] They occur abundantly in

[a] Bull. Geol. Soc. America, vol. 3, 1892, p. 374. [b] Am. Jour. Sci., vol. 20, 1905, p. 349.

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portions of the Robinson beds and were referred to David White for examination. His report, dated December, 1905, is as follows:

After examining excellent sections of the peculiar little fossils in the limestone from California, I am disposed to regard them as foraminiferal and having nothing whatever to do with plants. The organisms seem to be composed of successively enlarged chambers in linear arrangement, although the two or three earlier chambers occasionally show a relative position suggesting spirality. The central area of each chamber wall is somewhat irregularly perforated after the manner of various foraminiferal genera. These perforations are irregular in form and appear to have thickened margins with a greater or less amount of columnar development. The external surfaces of the chamber walls do not seem under ordinary magnification to exhibit either the perforations or the structure which are to be expected in coralline algæ.

While possessing no systematic knowledge of the Foraminifera, I venture the opinion that the species is distinct from, though probably related to, *Loftusia columbiana*, though at the same time I should question its reference to the genus *Loftusia*.

The only closely related fossil reported elsewhere in the Carboniferous of the Sierra Nevada is noted by Turner in the Bidwell Bar

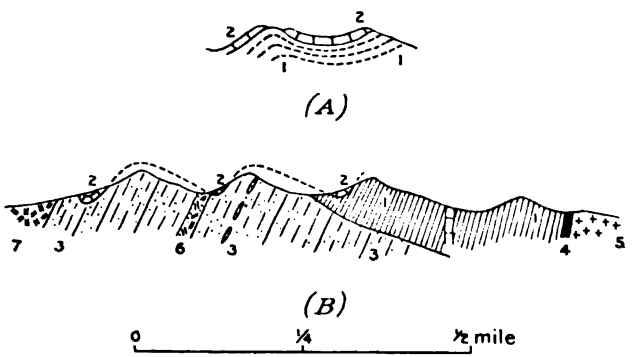

FIG. 5.—Sections of spurs north of Genesee Valley near Robinson's. 1, Swearinger slate; 2, Hosselkus limestone; 3, Robinson formation; 4, contact zone (hornfels); 5, granodiorite; 6, Reeve meta-andesite and tuff; 7, Taylor meta-andesite.

folio, page 3, from Edmanton, about 10 miles southwest of Quincy. The original specimens on which Schuchert's determination was based are not available for comparison, but it is not improbable that they are identical with those of Genesee Valley and Klamath Mountains and that the Robinson formation occurs at Edmanton.

Relation to adjacent formations.—The older rocks to which the Robinson formation is related are the Taylor meta-andesite and the Peale formation upon the southwest, while the newer beds, the Hosselkus limestone, Swearinger slate, and Trail formation, lie upon the northeast. First as to the older formations. As stated in connection with the Peale formation, they are separated from the Robinson formation by a belt of Taylor meta-andesite. It is a volcanic rock with pronounced porphyritic structure. In some places the most prominent phenocrysts are plagioclase; at others they are augite. The tuffaceous conglomerate and sandstone of the

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Robinson formation are composed almost wholly of volcanic material erupted in connection with the effusion of the mass of meta-andesite. They dip to the southwest beneath the sheet of volcanics which was the source of their material. That they have been overturned is demonstrated not only by this inverted succession but also by the fact that both the meta-andesite and the Robinson formation dip southwest beneath the Peale beds, which, as the fossils show, are of still greater age.

The relation of the Robinson formation to the newer strata, the Hosselkus limestone and Swearinger slate, which lie mainly upon the northeastern border, is shown in fig. 5, *A* and *B*, which illustrates a section running across the points of limestone a mile and a half northeast of Genesee. In that locality the Robinson beds evidently lie unconformably beneath all the later formations with which they come into contact.

TRIASSIC.

HOSSELKUS LIMESTONE.

Lithologic character.—The Hosselkus limestone is dark blue on fresh fracture, but weathers light gray, and contains a few veins of white calcite. It is thin bedded and in some places decidedly slaty, forming prominent ledges on the divide between Genesee Valley and Hosselkus Creek, a mile northeast of the Hosselkus ranch, from which the limestone was named. It is well characterized by small ammonites. Although they are not only uncommon but indistinct, yet they readily serve as a means of distinguishing this limestone from any other. In the Redding region, where this limestone is particularly well developed, the upper part is lighter colored and more massive, with a spirifer-like shell, and the lower part thinner bedded and darker, with small coiled forms, but in the Taylorsville region no such differences are apparent.

Distribution and thickness.—The most important outcrops of this limestone are on the divide already indicated north of the Robinson place. It forms two hills on the crest, running nearly northeast for half a mile, then turns northwest and crosses the valley of Hosselkus Creek, but soon disappears. This continuous exposure is only about 2 miles in length, but an isolated outcrop occurs at each end along the strike, one at the head of a ravine tributary to Peters Creek and the other near the road a mile east of Hosselkus, increasing the total length of exposure to about 6 miles but not extending it beyond North Arm to the northwest or Genesee Valley to the southeast.

Several isolated outcrops of the Hosselkus limestone occur on the lower slope of Grizzly Mountains, a mile southwest of the mouth of Little Grizzly Creek. They contain irregular patches of cherty matter and traces of crinoid stems, both round and pentagonal. These

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outcrops are approximately in line and make an exposure nearly a mile in length. The general strike is N. 5° E., and the dip 70° NW. into Grizzly Mountains. Over 50 feet of limestone are exposed. Traces of red beds occur at its base, though it is for the most part directly in contact with the meta-andesite. Just above the limestone black flinty material occurs which suggests some of the Swearinger slate, and judging from the size and character of the limestone, as well as its fossils and association, there appears to be little doubt that this mass really belongs to the Hosselkus limestone.

Notwithstanding its restricted occurrence in the Taylorsville region, it is more widely distributed to the northwest in the Lassen Peak quadrangle, where it is included with other sediments in the Cedar formation. In the Redding quadrangle, where it has its greatest development, it is rich in fossils and remarkable for its lenticular character. The greatest thickness of the Hosselkus limestone in the Taylorsville region is about 140 feet.

Fossils and age.—The fossils collected from this limestone by Professor Hyatt and others in the Taylorsville region have not yet been fully worked up. A partial list is given by Hyatt:[a]

I. *Arcestes*—phylum of *A. tornati.*
Arcestes—phylum of *A. galeati.*
Arcestes—phylum of *A. bicarinati.*
Arcestes—phylum of *A. sublabiati.*
Badiolites, allied to *B. eryx* Mojsis.
Juvavites, allied to *J. erlichi* Mojsis.
Tropites, may be young of species occurring in *Halobia* slates.
Atractites.

Arcestes (I) is very abundant, but whether the other forms are abundant or not it is difficult to say at present. The materials gathered show that the rock is full of fossils, but these can not be obtained in any reasonable time by means of surface work. Besides the species mentioned, there is a form of *Acrochordiceras*, with finer costæ than those occurring in the Muschelkalk, a possible *Balatonites*, like *B. waageni* of the Noric, and some other fragments of ceratitinæ, all indicating a fauna rich in ammonoids, which will some day yield a good harvest to patient work.

Professor Hyatt concludes that the age of the Hosselkus limestone as indicated by the fossils is upper Triassic. To this list *Spiriferina* and fish vertebra, as determined by Stanton, were added last summer. This limestone has not yet been thoroughly examined for reptilian remains, such as J. C. Merriam has found in the Redding quadrangle, but as the limestone of the Taylorsville region is more altered and much less fossiliferous, reptilian remains are less likely to occur. In the Redding region the more massive upper portion of the Hosselkus limestone is characterized by the presence of *Spiriferina*, while the lower, darker, thin-bedded portion often abounds in small ammonites. In the Taylorsville region an attempt was made to determine the upper and lower sides of the limestone by its fossils.

[a] Bull. Geol. Soc. America, vol. 3, 1892, pp. 399–400.

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Spiriferina was found at only one point on the side adjoining the Swearinger slate. In this respect it agrees with the Redding region, and tends, as we shall show later, to confirm the view that the Hosselkus limestone on the crest of the divide north of Genesee Valley is overturned. It should be noted, however, that the small coiled forms of *Arcestes* are most abundant on the same side, which does not strengthen the view concerning the *Spiriferina*.

Relation to the Robinson formation.—The reference of the Hosselkus limestone to the upper Triassic and the Robinson formation to the upper Carboniferous indicates a decided gap between them, a gap which is at least partially filled in the more complete section of the Redding region, where a great thickness (over 1,000 feet) of andesitic and rhyolitic lavas, with 1,500 feet of overlying shales, sandstones, and tuffs of Triassic age, comes between the horizon of the Robinson formation and that of the Hosselkus limestone. It is evident, therefore, that in the Taylorsville region there is a decided interruption between the Hosselkus limestone and the Robinson formation. It is possible, however, that their contact in the Taylorsville region is a plane of displacement, and that the formations of the Redding region missing in the Taylorsville region may, in part at least, be thus accounted for. This matter will be considered more in detail in the discussion of the relation of the Swearinger slate to adjacent formations. (See fig. 5.)

SWEARINGER SLATE.

Lithologic character.—The Swearinger formation is composed chiefly of dark slaty shale, sometimes becoming more or less calcareous and at others decidedly siliceous, but the thin beds of limestone or chert form only a small proportion of the whole mass. In the side of the Swearinger slate adjoining the Hosselkus limestone thin lenticular beds of limestone become more abundant. They are generally dark, with irregular cherty or sandy layers, and fossiliferous.

Distribution.—The Swearinger slate has a very limited distribution in the Taylorsville region. Its best exposure is on the spur which we called "Triassic spur," running up from Swearinger's house and spring to the point of Hosselkus limestone near the crest where the area divides. A small part keeps southwest of the limestone and crosses over to the spur, which is chiefly of Robinson beds. On this spur, which has been called the "Carboniferous spur," near the limestone is the locality of Hyatt's "*Halobia* bed," while the *Monotis* bed, *Daonella* bed, and *Rhabdoceras* bed of Hyatt are on the "Triassic spur."

The main body of the Swearinger slate extends north along the eastern or northeastern side of the Hosselkus limestone for about 2½ miles from Genesee Valley, gradually narrowing to the northwest and finally disappearing. It could not be found along Hosselkus Creek,

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where the Trail formation comes into contact with the Hosselkus limestone, nor south of Genesee Valley, where the Trail formation comes in contact with the Robinson. The outcrop of the Swearinger slate in the Taylorsville region is limited along the strike to a distance of less than 3 miles and a width where greatest of about a third of a mile. Along the eastern border it is much altered in contact with the granodiorite of the region.

Thickness.—The greatest thickness of the Swearinger slate exposed along Genesee Valley, where measured, is about 200 feet, but the amount cut off by the granodiorite or covered by the overlapping Trail formation we have no means of estimating except by comparison with formations of the same horizon in other regions; such comparison indicates that the thickness is probably not over 400 feet.

Fossils and age.—The fossils of the Swearinger slate were discovered and described by the Geological Survey of California under Prof. J. D. Whitney. Our knowledge of the fauna was greatly extended by Prof. Alpheus Hyatt, who has published[a] lists of the forms found in the subordinate paleontological horizons within the formation. They need not be repeated here except to note that the form from these beds once regarded as *Monotis subcircularis* is now considered by J. P. Smith and others to be *Pseudomonotis*. Professor Hyatt regarded the Swearinger slate as belonging to the upper Triassic, equivalent to the upper Noric of the Alpine Triassic, and as far as I am aware this reference has not been changed essentially by the somewhat later researches of Professor Smith.

Relation to adjacent formations.—The general dip of the Swearinger slate is to the southwest beneath the Hosselkus limestone, and on this account it was at first supposed[b] to be older than the Hosselkus limestone. In the Redding quadrangle of Shasta County, where these Triassic rocks are extensively exposed and much less disturbed, Prof. J. P. Smith discovered that the *Pseudomonotis* horizon, corresponding to at least part of the Swearinger slate, is above instead of below the Hosselkus limestone.[c] A study of the same region as set forth in the Redding folio confirms us in the same opinion, and shows that in the Taylorsville region the Triassic has been overturned, reversing the natural order of superposition. Everywhere the Swearinger slate and the Hosselkus limestone are essentially conformable. In the Taylorsville region they do not appear coextensive, but this lack may be due to displacement.

The only other sedimentary formation with which the Swearinger slate comes in contact is the Robinson, and judging from their faunal relations, belonging, respectively, the one to the top of the Triassic

[a] Bull Geol. Soc. America, vol. 3, 1892, pp. 397–400.
[b] Idem, pp. 272 and 395.
[c] Jour. Geology, vol. 6, 1898, p. 778.

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and the other near the top of the Carboniferous, they must be in unconformable contact, and the discordance must represent a time interval of long duration, an interval which is represented in the Redding region, as already explained, by a great thickness of lavas overlain by 1,500 feet, chiefly of shales—the Pit formation, belonging to the middle Triassic. The conformity of the Swearinger slate and the Hosselkus limestone and the unconformity of both on the Robinson formation is shown in fig. 5, *A* and *B*, which illustrates a section near Robinson's place.

Beginning with the limestone on the left-hand spur, where it has been burned for lime, we find it contains fossils that identify it with the Hosselkus limestone of the next two spurs to the east. This spur is made up chiefly of slates in which no fossils have been found. The first ravine toward the right is cut in meta-andesite, the eastern side of which is tuffaceous and belongs to the Robinson formation. The tuff and calcareous sandstone both contain an abundance of Carboniferous fossils, and in connection with the tuffaceous conglomerate which underlies the sandstone they form the second spur of the section, fig. 5, *A*, up to an elevation of 4,500 feet. Above that point, as shown in fig. 5, *B*, the spur is composed of *Halobia* beds of the Swearinger slate overlain by the Hosselkus limestone, and both are fossiliferous. They form an arch over the spur to both ravines, down which they extend far enough to appear in fig. 5, *A*. The strike of the Robinson formation on the lower part of the spur carries them unconformably beneath the Triassic arch, and it is evident that the line of contact between Paleozoic and Mesozoic is one of displacement, along which the overturned Triassic was shoved eastward across the truncated edges of the Robinson formation. The local disappearance of the Swearinger slate between the Hosselkus limestone and the Robinson formation is most likely due to displacement.

JURASSIC.

GENERAL ACCOUNT.

There are seven Jurassic formations of the Taylorsville region. The Trail formation is the oldest; then follow the Hardgrave sandstone, Thompson limestone, Mormon sandstone, Bicknell sandstone, Hinchman tuff, and Foreman formation in regular succession. With the exception of the last their surface distribution is limited to a comparatively small area about Mount Jura, and to facilitate matters it may be stated here that the whole set of beds have been overturned and that the Hardgrave sandstone apparently lies on top. In their attitude they are like the Triassic and Carboniferous, already described. The strike is northwest and the dip southwest.

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TRAIL FORMATION.

Lithologic character.—The Trail formation includes a mass of strata composed largely of slaty shales with some interbedded sandstones and conglomerates. It is well exposed along Hosselkus Creek on the trail, hence the name. The shales are often purplish or red, but perhaps more frequently gray, with pencil structure locally developed, and contain in places numerous cherty nodules of carbonate of lime. Well-marked slaty structure is not uncommon. The sandstones are generally fine, often somewhat slaty, are thin bedded, and vary from gray to almost black. The conglomerates of slate and sandstone pebbles, sometimes 3 inches in diameter, generally contain much volcanic material. Approaching the contact with the granodiorite in many places the fine sediments become darker and more compact, with conchoidal fracture, and pass into regular hornfels, a specimen of which from Hornfels Point is No. 134 in the Educational Series of Rocks.[a] Some of the beds of tuff are well defined, ranging from 10 to 50 feet or more in thickness, and occasionally coarse. Tuffaceous conglomerates are most abundant on the side toward the Swearinger slate, but extend throughout the formation, and a strip of 50 feet of slaty conglomerate occurs in the volcanics which bound the sediments on the northeast.

Distribution.—There are two principal areas of the Trail formation, one north of Genesee Valley and the other south. That north of Genesee Valley is blunt wedge-shaped, with its base 2 miles in width along Hornfels Point, where the sediments have been greatly altered by the underlying granodiorite. This area borders the Swearinger slate and Hosselkus limestone, crosses Hosselkus Creek, but is cut off by the volcanics before reaching the Lucky S road. From near its southeast corner it sends off two irregular projections. The long, narrow strip running northwest across Hornfels Point to Hosselkus Creek is chiefly slaty, sometimes pebbly shale. The bedding dips 83° SW. and strikes N. 50° W., parallel to the course of the belt, which is in places only 60 feet in width, and is bounded on both sides by volcanic rocks related to metaaugite andesite. The projection running east lies between the granodiorite and the volcanics. Much of it is greatly altered by the underlying granodiorite, and, consisting largely of volcanic material, may perhaps belong with the volcanics on the north rather than to the Trail formation.

From Genesee Valley the Trail formation extends southeast to the basalt flows of Ingalls Peak. It lies between the granodiorite on the one hand and andesite porphyry on the other, except for a short distance northeast of Genesee mine, where it comes in contact with the slates of the Robinson formation. The total length of the exposure of the Trail formation along the strike is about 7 miles and is limited in both directions by volcanics.

[a] Bull. U. S. Geol. Survey No. 150, 1898, p. 337.

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Thickness.—The thickness of the Trail formation was measured on the prominent spur next north of Hornfels Point descending into the sharp bend of Hosselkus Creek and found to be about 2,900 feet.

Fossils.—Fossils have been carefully sought for in the Trail formation, but with little success. However, traces of plants and animals have been found together at an elevation of 5,600 feet on the next spur north of Hornfels Point, and also a half mile northeast of the Gruss mine at an elevation of 4,700 feet south of Genesee Valley. Nothing whatever could be made of the plants, but of the other fossils Stanton reports "undetermined small bivalves, possibly *Estheria*, a crustacean. It is a nonmarine genus occurring in fresh or brackish water and is a common form in the Trail beds. Similar fossils occur in the Carboniferous as well as in Triassic and later formations." It is evident therefore that the fossils furnish little aid in determining the taxonomic position of the Trail formation. For this we must depend chiefly upon its apparent relation to the Swearinger formation.

Relation to Swearinger formation.—The general dip of the Trail formation on the measured section is southwest at an angle ranging from 35° to 80°, and it passes directly beneath the Swearinger slate and Hosselkus limestone. Attention has already been called to the fact, well illustrated in the Redding region, that the Swearinger slate is younger than the Hosselkus limestone and that in the Taylorsville region it has been overturned. This overturning includes also the Trail formation, and indicates that the Trail formation is the one next newer than the Swearinger. It seems evident also, from the way in which the Trail formation overlaps first the Swearinger slate and then the Hosselkus limestone to the Robinson formation, that the Trail formation is unconformable on all of them. The only other rocks, besides those just mentioned, that come in contact with the Trail formation are granodiorite and the various volcanics by which the Trail formation has been covered and its exposures limited.

Correlation.—The horizon of the Trail formation, as far as it can be made out in the Taylorsville region, appears to be unconformably over the Swearinger slate, in essentially the same relative position as the Modin formation of the Redding quadrangle at the base of the Jurassic sediments. Lithologically the two formations are similar and may be regarded as approximately equivalent, but this correlation secures no direct support from the paleontologic evidence. The Modin formation is locally rich in fossils and they occur in many places, although there are many other places where none could be found. Stanton compared the two faunas and reports that "*Estheria* has not been found in the Modin formation, but its absence from that formation is to be expected because all the fossils known from it are marine. The fossils present no serious objections to regarding the Modin and Trail beds as time equivalents."

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The relation of the Trail formation to the Hardgrave sandstone, which in the Taylorsville region is its successor, will be considered with the later formation.

HARDGRAVE SANDSTONE.

Lithologic character.—The Hardgrave sandstone is red or gray in color. It varies from fine shaly sandstone to conglomerate and is almost wholly of a tuffaceous character. The most common color is red, ranging from brick red to dull brown, but much of it is gray, and the two colors are intermingled irregularly in the same bed. The bedding is generally well marked, but in a few localities the massive outcrops show little trace of stratification. Where the sediments are fine the sandstone passes into shale, which occasionally shows a decided slaty cleavage and breaks up into long, slender, pencil-shaped fragments. Generally the sandstone is so fine as not to appear granular and breaks with a splintery fracture. The rock is firmly lithified and yet is comparatively soft, owing to the weakness of the calcareous cement. When the coarser forms of Hardgrave sandstone are broken the fracture generally passes around the grains instead of through them, allowing them to stand in relief upon the fracture surface and make it rough. Rarely it is hard and flinty, much fractured, and veined. In acid both the red and gray varieties effervesce freely, and locally they contain small limy patches. Carbonate of lime is the principal cement, but in the red and weathered forms oxide of iron plays an important part. Near its contact with igneous rocks it is colored yellowish green by epidote. Coarse gray sandstone and fine conglomerate are much less abundant than the finer forms. They afford a much better opportunity to see the volcanic character of the material. It is mainly volcanic sand, made up of crystal fragments of plagioclase feldspar with many lapilli, usually more or less vesicular, and often filled with minute lath-shaped crystals of feldspar, which are for the most part so altered that their polysynthetic twinning, if present, can not be seen. Many of the feldspar fragments are plagioclase, but a somewhat smaller number appear to be orthoclase and possibly some quartz. One of the striking features of this sandstone, apparent only on microscopic examination, is the paucity of quartz.

Distribution.—The Hardgrave sandstone is limited in its distribution within the Taylorsville region almost exclusively to the slope of Mount Jura, and occurs in two belts. One, the main belt, lies along the western base of Mount Jura, and the other, the crest belt, lies near the crest of the prominent spur running south from the summit of Mount Jura.

The main belt, wavy in its course, runs southeast almost continuously along the western base of Mount Jura from North Arm, near

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Dead Fall Lane, to Huntington's, and beyond to the lower slope of Grizzly Mountains, where two small areas mark its termination against a great mass of ancient quartz porphyry. The total length of this belt is a little over 4 miles, with a width ranging from a few feet to a third of a mile. This belt is the most accessible, and, lying on steeper slopes, contains better exposures than most of the other areas. Coarse gray calcareous sandstone, weathering very rough, crops out at a number of points along the western border, and east of it the finer red and gray beds occur. They are well exposed by the road a short distance northeast of Taylorsville, opposite the steel bridge, and about a mile farther southeast, near Donnerwirth's, but outcrops occur throughout the greater portion of the belt, though somewhat less abundant and conspicuous than those of the meta-andesite next eastward. The strike of the beds everywhere is approximately parallel to the course of the outcrops, and the dip is westerly. The interruptions in this belt east of Taylorsville, opposite the mouth of Montgomery Creek and on the lower slope of Grizzly Mountains, are due chiefly to the eruption of the meta-andesite.

The next most important area is the one which parallels the first in the crest belt. It is a narrow belt extending a little east of south from the summit of Mount Jura along the crest overlooking Hinchman Ravine. In lithology and fossils it is in the main identical with the belt just noted, but near the summit is somewhat more crushed and veined.

Between these two belts on the western slope of Mount Jura there are five smaller masses, three of which lie directly southwest of the Jura summit, one farther south, and another, the largest of the separated masses, lies a little farther north. A more isolated small area lies at an elevation of 4,500 feet on the northern end of Mount Jura, near the old lime road.

There is only one other area to mention, and that is one of the smallest and most isolated. It is about three-fourths of a mile northeast of the stage road at the crossing of Hinchman Ravine, and was discovered by the indefatigable Curtice. Lying outside of the area marked out by the two belts on Mount Jura, its degree of isolation is very much greater than that of any of the other areas in the region. The identification of all these isolated masses rests on paleontologic as well as lithologic evidence, and the attitude of the strata with westerly dip is essentially the same in all the areas.

The extremely limited and patchy distribution of the Hardgrave sandstone within a few square miles about Mount Jura is a striking feature. It does not occur anywhere else in the Sierra Nevada, but 80 miles to the northwest it has an extensive development along the border of the Klamath Mountains in connection with the Potem formation. The interval is now covered largely by the lavas of Lassen

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Peak, but during the Jurassic the two areas must have been directly connected.

Thickness.—The maximum thickness of Hardgrave sandstone as measured half a mile north of Donnerwirth's may be 850 feet, but is possibly much less, for the measurement involves a large talus-covered slope in which the limit of the sandstone could not be definitely determined. At a number of points in the same belt 250 feet of red and gray beds are well exposed. In the crest belt running south from the summit of Mount Jura two measurements were made. One-third of a mile from the summit the Hardgrave sandstone is 112 feet in thickness, and three-fourths of a mile from the summit, near the crest at the head of a prominent spur descending southeast to the mouth of Hinchman Ravine, it is 124 feet in thickness; the upper 54 feet are gray sandstone partly coarse, while the lower 70 feet are red. It is evident that in the main belt the sandstone is much thicker than in the crest belt. It decreases in thickness and runs out against older formations to the south, but northward it may continue its thickness beneath newer formations.

Age.—The paleontologic investigations of the Hardgrave sandstone were made by the late Prof. Alpheus Hyatt, whose preliminary report is as follows:[a]

The Hardgrave sandstone contains the remains of a very abundant fauna and the fossils are sufficiently well preserved.

The most abundant species are the following: *Pecten acutiplicatus*, Meek, is to be expected wherever this sandstone occurs, and can be called its characteristic fossil in this region; *Entolium meeki* is perhaps the next in abundance and is almost as widespread in distribution; *Pinna expansa* is not found everywhere, but it forms banks like *Ostræa* or *Unio* in some places and is often found associated with the two above named.

The age of the Hardgrave has been determined by cumulative evidence. That it was probably a member of the Lias, as previously stated by Prof. Jules Marcou, became evident after a preliminary examination of the fossils, but the facts leading to the conclusion that it is more likely a member of the upper Lias than of the lowest Lias were more difficult of acquisition. It contains many fossils having affinities with those of the lowest or infra Lias, and the *Modiola* and *Mytilus* might even have occurred in the uppermost Trias or Rhætic. On the other hand, some forms have very close relations to the same genera as they appear in the Mormon sandstone, or Oolite, of the same locality. *Pinna*, *Gervillia*, *Ctenostreon*, *Entolium*, *Trigonia*, and *Cidaris* show an assemblage of upper Lias types. The species of *Entolium* and *Ctenostreon* are closely related to those of the Oolite above, and one species of *Trigonia* resembles the young of a species from the Oolite of western Europe. The most conclusive evidence, however, is furnished by the single well-preserved specimen of *Glyphea*, which I was so fortunate as to find in the typical locality close to the village of Taylorsville, and the *Goniomya*, allied to *G. v-scripta*, Agassiz.

The 42 species exhibited, which were selected from the collections of the Geological Survey, do not represent the entire fauna. I have still further restricted the list given below to those species which are either characteristic or have been described and figured or can be closely compared with representative European species.

[a] Bull. Geol. Soc. America, vol. 3, 1892, p. 401.

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Taylorsville, Cal.	Europe.
Montlivaultia, n. sp. (?)	*M. haimei*, Chap. et Dewal.; lower Lias.
Ostræa, sp	*Ostræa irregularis*, Chap. et Dewal.; inferior Lias to middle Lias.
Ostræa, n. sp	*Ostræa arietis*, Quenst.; lower Lias.
Anomia, n. sp	*Anomia striatula*, Terq. et Piette; lower Lias.
Modiola, n. sp	*Modiola psilonoti*, Quenst.; lower Lias.
Mytilus, n. sp	*Mytilus psilonoti*, Quenst.; lower Lias.
Mytilus, n. sp	*Mytilus terquemianus*, Chap. et Dewal.; lower Lias.
Pinna expansa, n. sp	*Pinna hartmanni*, Auct.; lower Lias.
Gervillia linearis, n. sp	*Gervillia lanceolata*, Quenst.; upper Lias.
Gervillia gigantea, n. sp	*Gervillia aviculoides*, Quenst.; Oolite.
Gervillia gigantea, n. sp	*Gervillia betacalcis*, Quenst.; middle Lias.
Lima, n. sp	*Lima nodulosa*, Terq. et Piette; lower Lias.
Lima, n. sp	*Lima charta*, Dum.; lower Lias.
Lima, n. sp	*Lima galathea*, Dum.; upper Lias.
Ctenostreon, n. sp	*Lima tuberculata*, Dum.; lower Lias.
Pecten acutiplicatus, Meek *Lima sinuata*, Meek *Lima recticostata*, Meek	*Lima acuticostata*, Schübl.; inferior Oolite.
Pecten, n. sp	*Pecten textorius*, Goldf.; Lias and Oolite.
Pecten, n. sp	*Pecten dextilis*, Münst.; Lias and Oolite.
Entolium meeki, n. sp	*Pecten demissus*, Goldf.; Lias and Oolite.
Goniomya, n. sp	*Goniomya v-scripta*, Ag.; upper Lias.
Pholadomya, n. sp	*Pholadomya ambigua*, Sow.; upper Lias.
Pleuromya, n. sp	*Pleuromya striatula*, Dum.; upper Lias.
Trigonia, n. sp	*Trigonia costata*, Sow.; middle Lias.
Trigonia, n. sp	*Trigonia costatula*, Lycett; inferior Oolite.
Cidaris, n. sp	*Cidaris*, Quenst.; upper Lias.
Glyphæa punctata, n. sp	*Glyphæa solitaria*, Opp.; inferior Oolite.

I showed the unique fossil *Glyphæa punctata*, of which the carapace (with the exception of the tip of the rostrum) is well preserved, to Prof. Walter Faxon, of the Museum of Comparative Zoology, well known as an expert carcinologist, and he at once placed it in the Jura under the name *Glyphæa*. *G. solitaria*, Opp., of the lowest Oolite, zone of *Trigonia navis*, is not only very close to our American form in the characteristics of the sutures of the carapace, but the surface has the rare sculpturing of punctation in place of the usual tuberculation found in most species of this genus, a peculiarity also characteristic of *G. punctata*. Such forms as these and the evidently close alliance and probable continuity of the fauna through migration with that of the Mormon sandstone suggest that the Hardgrave sandstone should be classed as upper Lias in spite of the large number of forms which are represented by species occurring also in the lower and middle Lias in Europe.

The homogeneous character of the rock and the association of fossils found in the larger masses of it led also to the conclusion that it represented only one bed in the upper Lias, but such minute researches as would have established this beyond question were not practicable.

Relation to adjacent formations.—The next sedimentary formation older than the Hardgrave sandstone is the Trail formation. They are not known to occur in contact or even near each other in the Taylorsville region, but from the fact that the Trail beds are fresh-

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water deposits and the Hardgrave sandstone marine, they may be assumed to be unconformable.

The sedimentary formation next newer than the Hardgrave sandstone is the Thompson limestone. They have not been found in actual contact, but sometimes near together, separated only by a sheet of meta-andesite. Their essentially parallel position when near together indicates conformability. The Hardgrave sandstone at several points is in contact with the Mormon sandstone, but, as we shall see later, it is the result of faulting.

The Hardgrave sandstone is almost everywhere in contact on the one hand with an ancient rhyolite and on the other with meta-andesite. The metarhyolite is on the western side of the Hardgrave sandstone and lies upon it. The sandstone throughout its course in both belts dips westward beneath the ancient rhyolite and is composed, as already pointed out, of lapilli and débris derived from the rhyolite. It is therefore younger than the rhyolite, and their position has been reversed by overturning.

The contact of the Hardgrave sandstone with the meta-andesite along its eastern border is less regular than that of the metarhyolite on its western. The dip of the sandstone is west, and in many places it appears to rest directly on the meta-andesite, which passes beneath it with the same inclination. In other places—and these are important—the igneous rock breaks through the bedding and incloses many fragments of the sandstone, showing clearly that its eruption took place after the sandstone was deposited. The included sandstone fragments may be distinctly seen at an elevation of 4,100 feet in the ravine about a mile north of Donnerwirth's, as well as at other points near the contact within the area of the meta-andesite. The fragments are generally small and red, with the lithologic character of the Hardgrave sandstone, but no fossils were found in them. Though the sandstone along the contact is not clearly altered, the igneous rock is often perceptibly finer grained near the border, owing to the cooling influence of the sandstone. There seems to be scarcely room for doubt that the meta-andesite is younger than the Hardgrave sandstone.

THOMPSON LIMESTONE.

Lithologic character.—The Thompson limestone is gray and somewhat shaly, and on its weathered surface in places are round, oblong, or irregular patches of darker more or less granular calcite, which at once suggests fossils, though their specific determination is a matter of difficulty. Where shaly it is generally red, highly argillaceous, and locally full of long, slender gasteropods, which weather out and leave the porous argillaceous skeleton of the limestone full of "screw holes."

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Areal distribution and thickness.—The Thompson limestone, like the Hardgrave sandstone, outcrops in two belts. The main belt crosses the west slope of Mount Jura, and the crest belt lies along the crest running south from the summit of Mount Jura.

The main belt is irregular and interrupted, extending south across the west slope of Mount Jura from Mr. Thompson's on North Arm to the lower slope of Grizzly Mountains, a mile southeast of Huntington's, and the most prominent and accessible exposures are near the north end, where it has been burned for lime. At Thompson's it forms a bluff, strikes N. 70° W., dips 40° SW., and has a thickness of 30 feet.

A mile to the southeast the limestone is interrupted and offset nearly half a mile to the east. At an elevation of 4,100 feet outcrops begin again and have furnished material for lime. The mass at this point has a thickness of 40 feet and curves in position from N. 53° W. to N. 28° W., with a dip of about 40° to the southwest. It contains a number of irregular forms supposed to be sponges. The bottom layer of limestone is massive, 6 feet in thickness, and has a rough weathered surface. Below the limestone reddish and gray beds are exposed interstratified with limy layers. Above the limestone are 10 feet of red shaly limestone or calcareous shales locally full of *Nerinea*, the screw-shaped gasteropod to which allusion has already been made. At this locality the limestone changes its course from southeast to southwest and follows a prominent spur toward Taylorsville. The red shaly limestone and calcareous shale is more abundant and continuous than the lentils of gray limestone, and the whole mass is folded and displaced in a complicated fashion along lines running southeast, producing a local extension in that direction before the general course is resumed a mile farther southwest. On the prominent spur running a little south of west from the summit of Mount Jura is a small isolated patch of red beds belonging to the Thompson limestone horizon. Their strike is N. 15° E. They are highly calcareous, fragmental in appearance upon a weathered surface, and contain small nodules and lenses of gray limestone as large as 18 inches in diameter. Traces of fossils appear in the gray limestone and also in the red beds, but none are well enough preserved for specific determination. On the next spur, half a mile farther south, is a small mass of gray limestone 10 feet in thickness with irregular cherty portions. It is directly in the course and horizon of the Thompson limestone, but no fossils were found in place at this point, though they occur near by in the talus and in place a mile farther southeast beyond the interruption. On the spur running up from the Narrows the calcareous red beds with the characteristic fossils of the Thompson limestone reappear and continue to the road above Huntington's. On the lower slope of Grizzly Mountains, in the southwest quarter sec. 7, T. 25 N.,

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R. 11 E., the terminal outcrops of this belt of Thompson limestone appear in three isolated ledges lying along a line extending nearly east and west. Some of the limestone outcrops strike N. 36° W. and dip 45° SW., a position which connects it directly with the Thompson limestone of Mount Jura, while other portions strike N. 70° E. and dip 50° SE.; probably as the result of a fault. The limestone exposed at this point ranges from 4 to 25 feet in thickness. It looks like the Thompson limestone but contains only traces of indefinite fossils. However, its general relations to other formations leave no doubt as to its horizon.

The only outcrop of Thompson limestone lying outside of the main belt just described is in the crest belt of exposures extending south from the summit of Mount Jura. It occurs near the top of the spur rising northwest from the mouth of Hinchman Ravine, at an elevation of about 5,100 feet, and contains the curious spongelike forms, while the associated red beds have definite characteristic fossils. The total thickness of the formation at this point is probably less than 20 feet and its outcrop is scarcely half a mile in length.

The Thompson limestone has not been identified anywhere beyond the immediate vicinity of Mount Jura. Considering its size and variability, this is not a matter of surprise.

Relation to adjacent formations.—The relation of the Thompson limestone to the meta-andesite that bounds it upon the west may be clearly seen on the northern slope of Mount Jura, near the end of the lime road, where the red calcareous beds, full of slender gasteropods, come into direct contact with the altered andesite. The fossils lie parallel to the surface of the volcanic rock, practically against it, without showing any alteration due to the presence of the igneous rock. This relation evidently indicates that the limestone was deposited upon the meta-andesite and is of later age. It has already been shown that the same meta-andesite is younger than the Hardgrave sandstone. The general dip of the Thompson limestone is to the southwest beneath the meta-andesite by which it is bounded in that direction, and both pass beneath the Hardgrave sandstone. All have been overturned together.

On the eastern side the Thompson limestone appears to conformably overlie the Mormon sandstone, though their actual contact is rarely exposed. A small mass of rhyolite separates them on the steep slope overlooking North Arm, but a short distance farther south they outcrop near together in parallel positions.

In SW. ¼ sec. 25, T. 26 N., R. 10 E., where the limestone turns abruptly and extends east for nearly half a mile, it appears to be held directly in a downward fold of the Mormon sandstone. The two isolated outcrops west and southwest of the summit of Mount Jura, as well as the one in the crest belt south of the summit, clearly show,

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as illustrated in fig. 11, that the Thompson limestone rests upon the Mormon sandstone, and that its taxonomic position is between the Hardgrave and Mormon sandstones. It must be remembered, however, that the strata of Mount Jura having been overturned, the younger are below.

Fossils and age.—Professor Hyatt[a] refers to the Thompson limestone as the *Opis* bed, and remarks:

> Mr. Diller's close and repeated investigations of the stratigraphy have placed the *Opis* bed below the Mormon sandstone in the chronologic series, and my studies, although they led me to incline to the opinion that the fauna was younger, have not succeeded in bringing to light any evidence that can be said to contradict his conclusions. The presence of a large form of *Nerinea* with the columella, showing the typical ridges of the normal forms of this group, indicates that this limestone is not older than the inferior Oolite, and if, as seems to be the case, it is older than the Mormon sandstone, it will probably be proved to be a member of the inferior Oolite.
>
> A large species of *Opis* is as abundant in some places as the *Nerinea*, and this genus, which is recorded in Europe as beginning in the Trias, is usually small throughout the lower and middle Jura. The only European species approximating to that of this limestone is the *Opis paradoxa*, as figured by Buvignier, which occurs in the Corallian of the upper Jura. A species of *Terebratula*, apparently identical with the large characteristic species of the Mormon sandstone, also occurs abundantly in this bed. There are also a number of small gasteropods and other fossils requiring further investigation.

MORMON SANDSTONE.

Lithologic character.—The Mormon sandstone consists prevailingly of sandstone, passing on the one hand into conglomerate and on the other into more shaly beds. The most common and characteristic member is a gray compact sandstone so fine that to the naked eye it does not appear granular. Its color becomes brown on weathering, and the rock frequently contains casts of a small *Rhynchonella*. Among the grains of which it is composed there are many of quartz and of feldspar, some of which is clear plagioclase with distinct twinning lamellæ. A few are of pale-green augite, but most of them are of indefinite clouded material in which here and there small lath-shaped crystals of feldspar may be seen, indicating their derivation from igneous rocks. There is a small amount of carbonate of lime present, and it becomes somewhat more abundant in the coarser forms. The conglomerate of the Mormon sandstone is generally greenish, but sometimes reddish. Its pebbles are in a few places mainly quartzite, but at most localities they are chiefly of meta-andesite with a few of metarhyolite, and range from one-eighth of an inch to 18 inches in diameter. Several pebbles of limestone were observed, but none contained fossils. In the conglomerate are masses of fine shaly red sandstone with decided pencil structure parallel to its stratification. This same sort of material occurs also to a limited extent entirely independent of the conglomerate, and in such cases it is thin bedded and finely stratified.

[a] Bull. Geol. Soc. America, vol. 3, 1892, p. 403.

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Distribution and thickness.—The Mormon sandstone, extending across Mount Jura from the lower slopes of Grizzly Mountains to North Arm, occupies a larger area than that of the Hardgrave sandstone and Thompson limestone combined. At both ends it is relatively broad, but in the middle portion it is divided into two belts, one on the west slope and the other near the crest, in positions corresponding to the two belts of Hardgrave sandstone and Thompson limestone.

At a narrow point in the wavy belt across the western slope of Mount Jura the following section was observed: Adjoining the eastern side of the Thompson limestone is 45 feet of massive gray sandstone with a rich fauna. This is succeeded farther up the slope by 30 feet of conglomerate and finally by about 20 feet of finely stratified red shaly sandstone, the "Inoceramus bed" mentioned by Professor Hyatt. The total thickness of this belt a short distance farther south increases to about 225 feet and the conglomerate becomes more prominent, but farther along again diminishes and is scarcely noticeable near the south end.

The crest belt, long and narrow, running south from the summit of Mount Jura is well exposed on the steep slopes facing Hinchman Ravine, and affords the following section: Adjoining the Thompson limestone is a mass of greenish conglomerate 150 feet in thickness. Part of it is coarse and it includes much andesitic material. Some greenish sandstone is interstratified with the conglomerate. Below this is a gray sandstone 400 feet in thickness well characterized by the little *Rhynchonella*. It includes some shaly beds and near the bottom traces of conglomerate. The total thickness, 550 feet at this point, is much greater than that on the western slope of Mount Jura.

The curved area on the lower slopes of Grizzly Mountains opposite the mouth of Hinchman Ravine is chiefly gray sandstone and represents the union of the crest belt and that which crosses the western slope of Mount Jura. Besides the characteristic Mormon sandstone fauna which it contains there are traces of other fossils, and it is possible that some Hardgrave sandstone is here included in the area marked Mormon formation.

The largest area of the Mormon sandstone lies on the north slope of Mount Jura, stretching from the summit to North Arm. It is chiefly gray sandstone but includes also a large amount of conglomerate, which occurs at various horizons in the mass. Near the western border, under the Thompson limestone, there is locally a small amount of conglomerate, in which the fine greenish cement and many of the smaller pebbles are composed almost wholly of andesitic material. Reddish conglomerate and red beds occur in the middle of the Mormon sandstone on the steep slope southeast of Thompson's, but the most important outcrop of conglomerate is nearly a mile farther east, on the edge of the valley about Lucky S road. It strikes N. 27° W.

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and dips 62° SW., and the mass is extremely variable in its composition, varying from thin lenses of red shaly sandstone with prominent pencil structure to coarse conglomerate in which some of the pebbles are 18 inches in diameter and the material almost wholly andesitic in character.

The only area of the Mormon sandstone yet to be noted is a small one which is entirely isolated. It occurs about 4 miles northeast of Mount Jura, in sec. 17, T. 26 N., R. 11 E., and contains compact gray sandstone well characterized by fossils. This mass of the Mormon sandstone is much more disturbed than the others. The sandstone is much fractured, permeated by small quartz veins, and along the western border is greatly sheared, producing slickensided slaty material.

Fossils and age.—Concerning the fossils of the Mormon sandstone, Professor Hyatt,[a] in his paper on the Taylorsville region, reports as follows:

> This bed contains the remains of a more varied fauna than that of the Hardgrave sandstone. In some places, especially upon spur 8 of Mr. Diller's map, the fossils are in excellent preservation; but in some localities merely superficial work does not give good results, the rock being apt to be very friable. Here as elsewhere the greatest treasures await resurrection at the hands of those able to dig deeply into the stony matrix.
>
> It is more difficult to point out the characteristic fossils in this bed than in the Hardgrave sandstone. *Lima dilleri* and *L. taylorensis*, *Ctenostreon*, *Trigonia*, and *Entolium* are apt to occur in all the outcrops. So far as the determination of age is concerned, however, the Ammonitinæ, although not abundant, afford the best evidence. These highly specialized forms, as has been pointed out by several of the most distinguished paleontologists in Europe, must have been extremely sensitive to the influence of the changes of the surroundings in passing from one geologic level to another, and have recorded these mutations in their own organizations. Even the encyclopedic Quenstedt continually expresses his satisfaction in turning from the uncertain indications afforded by the more generalized structures of other mollusca to the decisive chronologic evidence usually given by the fossils of this group. The list printed below contains a series of selected species, but many forms, especially among the smaller Pelecypoda, which have not yet been studied, are necessarily omitted.

Taylorsville, Cal.	Europe.
Terebratula	*Terebratula perovalis*, Sow., as figured and described by Quenstedt, is similar, but the American species has no dwarfed varieties; inferior Oolite.
Rhynchonella, n. sp	*Rhynchonella quadriplicata*, Zeit., as figured and described by Quenstedt; great Oolite.
Alectryonia, n. sp	*Orthis marshii*, Goldf., as figured by Mor. et Lyc. in Oolite Mollusca; inferior and great Oolite.
Modiola subimbricata, Meek, and also other species of the same genus similar to this, but having shorter and broader shells.	*Modiola imbricata*, Sow., and other species of *Modiola*, with heavy umbonal ridges, occurring in the inferior and great Oolite.

[a] Bull. Geol. Soc. America, vol. 3, 1892, p. 403.

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Mytilus, n. sp.	*Mytilus sublævis*, Mor. et Lyc., and other species, having arcuate forms and heavy umbonal ridges, which are characteristic of the Oolite.
Pinna cuneiformis, n. sp.	*Pinna cuneata*, Phill., as figured by Mor. et Lyc. in Oolite Mollusca; inferior Oolite.
Pteroperna, n. sp.	Stands between *Pteroperna plana* and *Pteroperna costatula*, Mor. et Lyc.; inferior and great Oolite.
Gervillia, n. sp.	*Gervillia lanceolata* of the upper Lias, but longer and narrower in proportion, and the posterior wing larger. It is in fact a more progressive form in the same series of species than *Gervillia lanceolata*.
Gervillia, n. sp.	*Gervillia aviculoides*, Sow.; great Oolite.
Lima dilleri, n. sp.	*Lima cardiiformis*, Sow.; great Oolite.
Lima, n. sp.	*Lima tenuistriata*, Münst. and Goldf.; inferior Oolite.
Lima taylorensis, n. sp.	*Lima rigidula*, Mor. et Lyc.; great Oolite.
Ctenostreon, n. sp.	*Ctenostreon pectiniformis*, Mor. et Lyc.; inferior and great Oolite.
Pecten, n. sp.	*Pecten disciformis*, Schübl.; inferior Oolite.
Pecten, n. sp.	*Pecten demissus-gingensis*, Quenst.; inferior Oolite.
Pholadomya, n. sp.	*Pholadomya fidicula*, Zeit.; inferior Oolite.
Trigonia, n. sp.	*Trigonia hemispherica*, Lyc.; inferior Oolite.
Trigonia, n. sp.	*Trigonia formosa*, Lyc.; inferior Oolite.
Belemnites, n. sp.	*Belemnites breviformis*, Voltz.; upper Lias to inferior Oolite.
Sphæroceras, n. sp.	*Sphæroceras gervilli;* inferior Oolite.
Grammoceras, n. sp.	*Grammoceras toarcense*, as figured by Buckman; inferior Oolite.
Grammoceras, n. sp.	*Grammoceras leurum*, Buckm.; inferior Oolite.

The fossils indicate the former existence of a fauna which can be provisionally considered as belonging to the upper part of the inferior Oolite.

Inoceramus bed.—Immediately above the Mormon sandstone with its rich fauna there are strata of a red sandstone containing very few remains and these usually in poor condition. Three species of fossils were found in them: A *Terebratula*, apparently the same as that occurring so plentifully in the typical Mormon sandstone; two fragments of a large species of *Inoceramus;* and a fragment of an ammonite of the genus *Perisphinctes*. The *Inoceramus* of the Jura is not so large in the Lias as in the Oolite, and these fragments appeared, therefore, to have belonged to shells at least as old as the Oolite. The specimen of the *Perisphinctes* may prove to be identical with some species found below. It is probable, therefore, that this bed belongs, as in fact is indicated by the geology, to the upper part of the Mormon sandstone. On the other hand, the fact that one out of the three species was new to the fauna of the Mormon sandstone justifies a provisional separation under a different title on biologic grounds. Even if not sustained by future work, this distinction will serve a good purpose if it succeeds in calling the attention of collectors in the same or other localities to facts that might otherwise escape their notice.

Relation to adjacent formations.—The Mormon sandstone is in conformable contact with the Thompson limestone, though it marks a decided change in the character of the sediment from fine calcareous

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to coarse fragmental derived chiefly from altered andesitic rocks. This relation may be best seen on the southwest slope of Mount Jura near Donnerwirth's, where the positions of both the above-named formations are practically parallel to that of the adjacent Hardgrave sandstone.

The isolated mass 4 miles northeast of Mount Jura rests unconformably upon the Hosselkus limestone, as shown in fig. 6, without the intervening Triassic and Jurassic strata. This discordance, however, is not of deposition but of dislocation along a line of extended faulting.

The relation of the Mormon sandstone to the later formations will be considered in connection with the Bicknell sandstone.

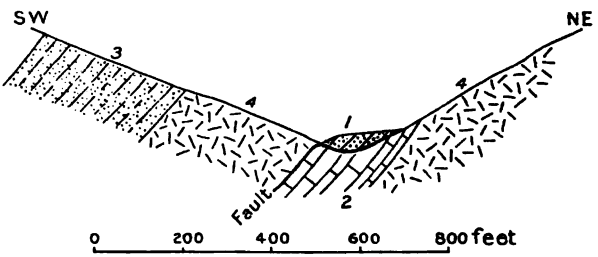

FIG. 6.—Relation of Mormon formation to Hosselkus limestone. 1, Mormon sandstone; 2, Hosselkus limestone; 3, Robinson formation; 4, eruptive rocks.

BICKNELL SANDSTONE.

Lithologic character.—The Bicknell sandstone is composed chiefly of red and gray sandstone associated with some dark shales and tuffaceous beds. The dark brownish-red sandstone is largely feldspathic and contains much red oxide of iron with more or less carbonate of lime. It somewhat resembles the red Hardgrave sandstone, but is darker colored, and though much of its material may be derived from igneous rock, its particles are not characterized by the presence of numerous small crystals of feldspar as in the Hardgrave sandstone. Sandstones, mottled gray and red, form transitions to the gray sandstone which is the most abundant rock of the formation. Much of it is fine dark bluish gray, very compact and hard, breaking with a conchoidal fracture, and flecked here and there by small particles of pyrite. It looks so much like hornfels that one is surprised to find it locally full of large shells. Associated with this form is more or less black shale, some beds of which weather white and look like fine volcanic dust. A thin section, however, shows no characteristic volcanic material, but instead extremely fine sediment with a multitude of minute microscopic crystals of rutile which have developed in the sediment since it was laid down.

A coarser variety of the sandstone is light gray or greenish and passes into a rock which is full of small white crystals of feldspar with

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a few scales of gray mica embedded in a dark groundmass, and the general aspect is decidedly igneous. The fact that it contains distinct fossils shows that it is fragmental, and it locally becomes coarse, so that its real character is more evident. In thin section under a microscope the fine fossiliferous rock is clearly fragmental, and much of the sediment was evidently derived from the erosion of volcanic rocks.

Distribution and thickness.—The Bicknell sandstone is much more regular in its distribution than the other Jurassic formations already noted and forms a continuous belt from the mouth of Hinchman Ravine across the east and north slopes of Mount Jura to North Arm of Indian Valley. Its greatest development appears to be on the southeast slope of Mount Jura, which is the only portion that is well characterized by fossils.

The reddish sandstone is the earliest portion of the Bicknell sandstone and lies near the west border of the mass. It is best exposed along the crest north of the summit. The compact fine dark-gray sandstone with the black shaly portions interbedded with gray sandstone forms the middle portion of the mass and becomes more tuffaceous along the east border where it adjoins the Hinchman standstone.

The thickness of the Bicknell standstone on the southeast slope of Mount Jura, where its greatest development occurs, is probably over 1,000 feet. From this point it appears to decrease in magnitude to the north and south so as to average less than 500 feet in thickness.

The general attitude of the Bicknell sandstone is like that of the Hardgrave, Thompson, or Mormon formations already noted. With but few exceptions it strikes west of north and dips southwest beneath Mount Jura.

Fossils and age.—In this sandstone fossils are neither so generally distributed nor so abundant as in the other Jurassic formations already noted. None have been found north of the summit of Mount Jura. Regarding this Professor Hyatt[a] says:

> The fauna of the Bicknell standstone is not so rich in species as are the Mormon and Hardgrave sandstones and the Thompson limestone, nor are the fossils so plentiful. The character of the rock in the surface exposures found by the party made it almost impossible to get out large specimens in perfect condition. Nevertheless, a sufficient number of molds of several large species of *Trigonia* (*T. obliqua* and *T. plumasensis*) and some well-preserved specimens of *Gryphæa bononiformis* were secured, all of which are more or less characteristic of the youngest faunas of the Jura in Europe.
>
> The remains of the Ammonitinæ are fragmentary, but those that were found certainly indicate a somewhat older fauna than the species above named. There are a number of the molds *Rhacophyllites* with the internal septa partly preserved, a fragment of a *Reineckia*, two rather poor molds of *Macrocephalites* (?), and several fragments of *Perisphinctes*. These form an association which gives strong support to the provisional opinion that the fauna is really synchronous with that of the Callovian, the oldest

[a] Bull. Geol. Soc. America, vol. 3, 1892, p. 406.

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fauna of the upper Jura, or Malm, in Europe. The specimens of *Chemnitzia* are molds of a very large shell, but unluckily do not show the aperture. The only species in Europe which appears to be a close ally of this is also from Callovian.

The list below gives a very inadequate idea of the fauna, since none of the belemnites or Ammonitinæ can be directly compared with European species on account of the need of more perfect specimens and are, with one exception, not mentioned. There are also a large *Nerinea* and a few species of Pelecypoda and Brachiopoda, which were not considered important in this preliminary notice.

Taylorsville, Cal.	Europe.
Gryphæa bononiformis, n. sp.	*Ostræa bononiæ*, Sauv., as figured by de Loriol et Pellat; Portlandian.
Entolium costatum, n. sp.	
Oxytoma, n. sp.	
Trigonia obliqua, n. sp.	*Trigonia michelloti*, de Loriol; Portlandian.
Trigonia plumasensis, n. sp.	*Trigonia lusitanica*, as figured by Choffat; Portlandian.
Trigonia naviformis, n. sp.	*Trigonia navis;* inferior Oolite.
Chemnitzia, n. sp.	*Chemnitzia athleta*, d'Orb.; Corallian.
Rhacophyllites, n. sp.	

The group of *Trigonia glabræ* to which *T. obliqua* belongs reached its acme in the Portlandian, the species being both rare and comparatively small in the Lias and inferior Oolite. *T. obliqua* is of extraordinary size and shows the incomplete costæ of the Portlandian species. The group of *Trigonia* to which *T. plumasensis* belongs is very peculiar in the characteristics of the costæ and the ornamentation of the anal area, and it has hitherto been represented in Europe only by the unique form, *T. lusitanica*, found only in the highest Jura of Portugal. Besides these two large species there is also in *T. naviformis* an equally large representative of another peculiar and hitherto unique style of ornamentation. This, as its name implies, is similar to *T. navis* of the inferior Oolite in Germany, a species hitherto considered to be the only representative of a very distinct group, the *Trigonia schapoidæ*, and having a pattern of costation not found in any other species (except *T. naviformis*) and a narrow chorologic range.

The group of the *Trigonia undulatæ* is represented by a species also of extraordinary size, but the *Trigonia clavellatæ*, the group more largely represented than any other in the inferior Oolite (if one can judge from the simple specimen obtained in the Bicknell sandstone) is not materially modified.

Bicknell tuff.—Above the sandstone and in immediate contact with it is a tuff described by Mr. Diller, which contains in part the same species as the sandstone, and the fossils indicate the same fauna. Nevertheless, it should be noticed that it contained no remains of *Trigonia*, and that the fauna has not been critically examined.

Relation to adjacent formations.—As to the relation of the Mormon and Bicknell sandstones, observations are not so definite, though they point to conformity. Upon the south slope of Mount Jura, as well as upon its north end, the two sandstones are separated by a belt of meta-andesite, but for nearly a mile north of the summit they appear to be in conformable contact. The actual contact was not observed, but throughout the two formations appear in parallel position. The adjoining formations are connected by transitional sediments and there is no decided interruption visible between them excepting a change in fauna.

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HINCHMAN SANDSTONE.

Lithologic character.—The Hinchman sandstone is composed essentially of coarse sandstone with shaly parts and some conglomerate which is generally fine and derived chiefly if not wholly from andesitic rocks. Much of it is decidedly tuffaceous. The most common form is greenish gray and contains darker colored shaly patches, but is not conspicuously fragmental. Examined microscopically it is found to be made up largely of fragments of feldspar, augite crystals, and varying proportions of andesitic rock, fragments of which are clearly microporphyritic. The feldspar is generally much altered. Some of the augite is fresh, but most of it is altered to chlorite, giving a greenish color to the rock. It is never coarse like volcanic agglomerate, though it is sometimes made up largely of ejected volcanic material, some of which is clearly pumiceous. The grains are rarely well rounded by attrition, though it is evident that they have been transported and loosely aggregated on the sea floor, affording corners and cavities where corals, belemnites, and a number of other marine forms flourished. Remains of these animals are not confined to one horizon, but are scattered throughout the formation. The conglomerate locally becomes coarse and composed of pebbles, some of which are well rounded; others are angular. The largest pebbles are rarely a foot in diameter. One of the most abundant types is a reddish, decidedly microporphyritic andesite. Others less common are dark and macroporphyritic, with either feldspar or hornblende phenocrysts. Limestone pebbles or nodules occur sporadically, but none could be found with fossils.

Distribution and thickness.—The outcrop of the Hinchman sandstone is confined to the slopes of Mount Jura, and stretches in one continuous belt from the mouth of Hinchman Ravine to the borders of North Arm. Like the other formations of Mount Jura its general strike, without much variation, is a few degrees west of north and its dip to the southwest. Its best exposures are at Curtice Cliff, in the lower part of Hinchman Ravine, where most of the fossils were collected, though they occur also along the crest on the northern slope. The greatest variation from the normal Hinchman tuffaceous sandstone occurs in the coarse conglomerate with well-rounded pebbles along the west slope of South Fork of Foremans Ravine. This conglomerate somewhat resembles that of the Mormon formation exposed by the Lucky S road on the flat near Foreman and its strike appears to connect it with that mass. No fossils could be found in it, and the stratigraphy of the west slope of the South Fork of Foremans Ravine places it in the upper part of the Hinchman sandstone as here considered. This conglomerate ranges from 50 to nearly 200 feet in thickness and was not recognized in Hinchman Ravine, where the tuffaceous portion of the formation has its greatest development and attains a thickness of 500 feet.

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Fossils and age.—The most widely distributed and characteristic fossils of this horizon are corals which Professor Hyatt relegates to the genus *Stylina* and has designated the bed in which they occur "*Stylina* bed." He reports further[a] in the paper previously referred to that—

The presence of the same species of *Rhacophyllites* as that found in the Bicknell sandstone indicates the continuity of the fauna of this bed with that of the preceding; but, on the other hand, the absence of *Trigonia* and the presence of close allies of *Ostræa bruntrutana* and of *Pecten suprajurensis*, shows that we have ascended in time to a younger fauna. The abundance of corals of the genus *Stylina*, these being the most widely distributed and characteristic fossils of the Hinchman tuff, shows that the age is probably that of the Corallian. In Europe these corals are rare in the Oolite, but reach their acme in numbers of species and forms in the Corallian of the upper Jura. The opinion expressed with regard to the age of the Bicknell sandstone is greatly strengthened by this fact, and it also adds to the evidence that the subdivisions of the Jura in North America and in Europe, like those of the Trias, may be compared much more closely than one would at first suspect from the extremely fragmentary records heretofore found in this country.

The fossils occurred in patches and, although abundant, good specimens were not easily obtained. The list is as follows:

Taylorsville, Cal.	Europe.
Gryphæa curtici, n. sp	*Ostræa bruntrutana*, as figured by de Loriol; Corallian to Portlandian.
Camptonectes bellistriatus, Meek	*Pecten suprajurensis*, Buvignier; Kimmeridgian.
Chemnitzia	*Chemnitzia athleta*, d'Orb.; Corallian.
Rhacophyllites (same species as in the Bicknell sandstone).	
Stylina tubulifera	*Stylina tubulifera*, Ed. et H.; Corallian. *Astrea tubulifera*, Goldf.; Corallian.
Stylina subjecta, n. sp	Closely allied to a specimen in Museum of Comparative Zoology named *S. echinulata*, Lmk.; Corallian.
Stylina alba, n. sp	
Stylina minuta, n. sp	Resembles the Cretaceous species figured by Goldfuss as *Astrea geminata* (equal *S. geminata*, Ed. et H.), but septa are not so symmetrical.
Stylina intermedia, n. sp.	
Stylina tertia, n. sp.	

Two species of *Belemnites* and a number of gasteropods, pelecypods and brachiopods were also found in this bed.

Relation to Bicknell sandstone.—The Hinchman and Bicknell sandstones are conformable and connected by intergradation, so that, though the Bicknell sandstone is prevailingly fine and the Hinchman prevailingly coarse tuffaceous sandstone, there is no sharply traceable boundary between them. The general lithologic differences, in addition to the faunal contrasts pointed out by Professor Hyatt, furnish sufficient grounds for distinction. Nevertheless, these two formations have greater similarity than any other two of Mount Jura.

[a] Op. cit., p. 407.

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FOREMAN FORMATION.

Lithologic character.—The Foreman formation is a succession of shale, sandstone, and conglomerate in which the sediment is for the most part derived from rocks which are not clearly volcanic. The shales are often slaty and locally have "pencil structure," and range in color from dark carbonaceous with traces of leaves through gray, which predominates, to shades and tints of red and yellow. A remarkable feature of the shales locally is their pencil structure, which is particularly well developed in the summit of Evans Peak. The beds of red and gray sandy shales making the summit of the peak break up into small columns, often of lead-pencil size, but generally smaller. They are less commonly larger, reaching a maximum length of 7 inches and a diameter of about half an inch. The pencils are commonly four sided and diamond shaped or rhombic in cross section, but occasionally they have three or five sides.

Almost as abundant as the shales are the sandstones, most of which are very fine and decidedly shaly. They are reddish brown and gray, sometimes mottled with darker spots, chiefly carbonate of lime. These spots weather out more easily than the other parts and leave the rock with occasional holes in its surface. Occasionally the gray sandstone is more siliceous and contains irregular particles which give to the mass the appearance of a fine tuffaceous conglomerate.

Conglomerate is less abundant than either shale or sandstone and is usually in thin beds of small extent scattered throughout the formation. The most characteristic conglomerate of this formation is composed almost wholly of small pebbles of cherty quartz, black and gray in color, and rarely over half an inch in diameter. Of this there are but few beds ranging from 5 to 12 feet in thickness. A more abundant form of conglomerate contains locally many shale fragments and well-rounded pebbles chiefly of meta-andesites and rhyolites, with a few of fossiliferous limestone. The majority of the beds are small and are made up of small pebbles, rarely as large as 3½ inches in diameter. Associated with the limestone pebbles in the conglomerate are concretionary nodules of carbonate of lime, which occur also in the shale and sandstone. They do not contain fossils and grade into the inclosing rock instead of having a sharp contact, as is the case with the limestone pebbles.

Distribution and thickness.—The Foreman formation occupies a larger area than all the other Jurassic formations of that region combined, and extends from Genesee Valley northwest to Mountain Meadows, a distance of 13 miles. Two interruptions occur in the belt, one near Hinchman Ravine by meta-andesite, and the other at North Arm, where it is covered by alluvium. At the northwest end of the exposure the Foreman beds disappear in the same way by passing beneath the alluvium of Mountain Meadows and the lavas

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of the great volcanic field beyond. The small area on the border of North Arm, a mile north of Peters Creek, is the edge of a large connecting mass which underlies the alluvium of North Arm, but the two small areas, one on Lights Creek and the other on Surprise Creek, are entirely isolated. Though the formation is composed of interstratified shale, sandstone, and conglomerate throughout, these rocks are so distributed that the formation may be roughly divided into three members of about equal thickness. The upper or oldest mem-

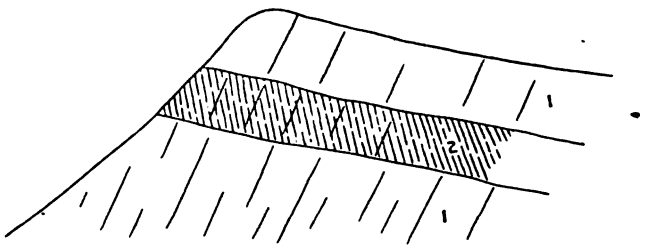

FIG. 7.—Section of interbedded shale and sandstone of Evans Peak, showing relation of joint and pencil structure. 1, Jointed structure of sandstone and shale; 2, pencil structure of shale.

ber, along the west border of the formation, is composed very largely of dark shale with a few beds of fine cherty quartz conglomerate and contained nearly all the fossils thus far collected from the formation; the middle member is chiefly gray sandstone with a few traces of fossils, while the lower or youngest member, lying along the east border, is made up largely of gray shales and as far as yet known is without fossils.

The Lucky S road affords a good section of this formation, especially of the cherty conglomerates, in its older portion near the western border, but the most continuous exposures occur on the steep slopes of Evans Peak, where 1,600 feet of strata outcrop. All three members are well exposed in the Evans Peak section, and shales predominate, interstratified with sandstone and numerous layers of conglomerate. As already noted, the shales are remarkable for their highly developed pencil structure. The shales dip to the southwest and are cut by joints having about the same strike and a somewhat steeper dip to the northeast. The joint planes are usually very rough, due to the impinging of the pencils, which are vertical. The general relations of the stratification to the jointing and the vertical pencils are shown in fig. 7, and the plan of the pencil-making fissures on the plane of stratification in fig. 8. The planes bordering the pencils are not clearly slickensided, and yet they may have been planes of motion to produce the several sets of slaty cleavage which divide the mass

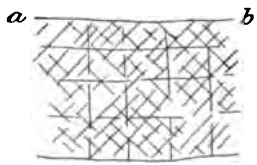

FIG. 8.—Plan of pencil structure on plane of stratification. *a–b*, Strike.

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into pencils. The pencil structure of the sandy shales, although best developed on the slopes of Evans Peak, occurs on Peters Creek and elsewhere locally in the finer sediments of the Robinson beds, as well as in the formations of Mount Jura.

Fossils and age.—Fossil plants were discovered near Foreman in dark shale close to the west border of this formation by Cooper Curtice in 1890, and at a later date the small collection was somewhat enlarged by E. G. Paul and James Storrs. Professor Fontaine studied the collection and described[a] the plants, and his conclusions are as follows:

The plants are very fragmentary, and most of them are poorly preserved. The most distinct are a small *Equisetum* and several ferns with small pinnules. The ferns are the most numerous, but unfortunately they present mostly such portions as the tips of pinnæ and detached fragments of pinnæ. The amount of material is not sufficient to enable one to determine with positiveness their relations to previously described forms, for ferns are so notoriously variable in foliage that a considerable amount of material is needed to make reliable determinations. Still, taking the collection as a whole, and looking to the nearest relationships with previously known fossil plants, we may arrive at some results with a considerable degree of certainty.

The plants are certainly younger than Paleozoic, and as the elements of the flora are ferns, equiseta, cycads, and conifers, with no trace of dicotyledons, they are Mesozoic, most probably older than Cretaceous, with the possible exception of its very base.

Owing to the imperfection of the material and the absence of the type forms, I can not come to a positive conclusion as to the exact position in the Mesozoic of these plants, but I think the weight of evidence is strongly in favor of the flora being Rhætic or uppermost Trias.

In a paper on the geology of the Taylorsville region of California,[b] the Foreman beds, on the evidence afforded by the plants, were relegated to the top of the Triassic. At that time only a few traces of fossil animals were known in the Foreman beds. A belemnite, a gasteropod, and a cast of a bivalve shell, with traces of plants, had been found about a thin layer of dark bluish limestone at the head of Starks Ravine, near the south line of sec. 35, T. 27 N., R. 10 E., about 3 miles southeast of Evans Peak.

Further collections of fossil plants were made at the same locality by James Storrs in 1904 and submitted to F. H. Knowlton, who reports as follows:

Acrostichites ? princeps (Presl.) Schenk.	Equisetum munsteri (Stb.) Brongn.
Acrostichites brevipennis Ward.	Podozamites ? sp.?
Sagenopteris ? sp.	Conifers ? fragments.

These determinations are based on Fontaine's identifications of the earlier material from the same locality, as recorded in Ward's Status of the Mesozoic Floras, First Paper, pages 333, 334. I have not looked far enough into the question to have an opinion as to the bearing of these plants on the age, but I may say, after looking rather hastily over the earlier material, that I incline to question several of Fontaine's generic determinations. His *Podozamites ? taylorvillensis* is certainly a *Pterophyllum*, his *Sagenopteris* looks to me like *Glossopteris*, and his *Acrostichites* may prove to be *Gleichenia* or *Gleichenopsis*. (February 8, 1905.)

[a] Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 333.

[b] Bull. Geol. Soc. America, vol. 3, 1892, p. 373.

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The discovery of shells at a new locality in this formation by James Storrs in 1904 affords more important data for reference to a definite horizon. The shells occur in the older portion of the formation, near the plant beds, in approximately the same horizon as those of Starks Ravine. They were studied by T. W. Stanton, who reported January 20, 1905, as follows:

> The fossils were compared with the earlier collections from the same region studied by Professor Hyatt, and it was thus practicable to confirm Mr. Diller's field determinations of horizons, although in most cases the fossils are not specifically identified because the species have not been described.
>
> The only important change in our ideas concerning the relations of the various Mesozoic formations of the region is caused by the collection from the Foreman beds (No. 6776). This formation has previously yielded only a few fragmentary plants which were supposed to be Upper Trias (Rhætic). The present collections of marine invertebrates is sufficient to prove that at least a part of the formation is Middle Jurassic or later.
>
> The following lists, with brief comments, will indicate the character of the collection from each locality:
>
> 6776. South fork of Foremans Ravine, 3 miles northeast of Taylorsville.
>
> Pecten sp.
> Trigonia naviformis Hyatt ?...Fragments of this or a closely related species.
> Astarte sp.
> Perisphinctes ? sp.....Imprint.
> Ammonites.....Imperfect imprints of two genera.
> Belemnites.....Imprint.
> Several undetermined small pelecypods and gasteropods, represented by casts and imprints.
>
> This lot differs lithologically and in general faunally from any of the known fossiliferous horizons of the Taylorsville Jurassic.
>
> The *Trigonia* is convincing evidence that the bed from which it came is later than the Triassic, and the close relationship, if not identity, of this *Trigonia* with *T. naviformis*, as well as the character of several of the other forms, indicates that the horizon is in the Jurassic and later than the Hardgrave sandstone—possibly later than the Bicknell sandstone.

In reply to my question as to the faunal relation of these beds to the Hardgrave sandstone, Stanton stated that they may well be the youngest Jurassic beds of the region, even younger than the Hinchman. This statement of Stanton is confirmed by the stratigraphy of the region, which places the Foreman beds next younger than the Hinchman sandstone.

Relation to adjacent formations.—The general strike of the Foreman beds is northwest and the dip is to the southwest immediately beneath the Hinchman sandstone and all the other formations of Mount Jura which have been overturned. The contact between the Foreman and Hinchman strata is locally very irregular along the east side of Hinchman Ravine, and the lack of accord in the strikes of the two formations suggests a slight unconformity. Completely satisfactory evidence on this point could not be obtained, though it is supported by the fact that in the hills just east of Foreman the

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Foreman beds unconformably overlap the Mormon formation without the intervening Bicknell and Hinchman sandstones. Farther northwest, beyond North Arm, the Foreman beds come in direct contact with the metarhyolite and the Robinson formation without any intervening Jurassic and Triassic strata. Northeast of Mount Jura, at the head of South Fork of Foremans Ravine, the Foreman beds unconformably overlap the Peale formation of Carboniferous age but do not come in contact with any other sediments in that locality.

As bearing upon the unconformity between the Foreman beds and the Carboniferous formations, it may be noted here that fossiliferous limestone pebbles were found in the conglomerate of Evans Peak. In them Girty reports *Diphyphyllum* sp., *Amplexus?* sp., and *Archæocidaris* sp., and remarks that they are "certainly Paleozoic and probably Carboniferous."

SOUTHERN EXTENSION OF THE TRIASSIC AND JURASSIC ROCKS OF THE TAYLORSVILLE REGION.

The Mesozoic formations of the Taylorsville region are cut off by igneous rocks before reaching the fortieth parallel. Next south of that line is the Downieville quadrangle, which has been mapped and described in a folio by H. W. Turner. He recognizes two formations in the "Juratrias." The lower he regards as closely related to the Sailor Canyon formation, and the upper he designates the Milton formation. The distribution of these two formations, as far as it has been possible to separate them, is shown in Pl. I.

SAILOR CANYON FORMATION.

The lower portion is composed chiefly of siliceous argillite with some coarser sediments in part volcanic, and a layer of fine breccia of gray fragments in a dark matrix which contains radiolarian remains. An ammonite was found in the siliceous slates, which shows that they are closely related to the Sailor Canyon beds which Waldemar Lindgren discovered in the Colfax and Truckee quadrangles south and southeast of Downieville.

According to Lindgren black calcareous shale without pronounced fissility, interbedded with subordinate strata of quartzite and limestone possibly to the thickness of 6,000 feet, is well exposed with easterly dip along North Fork of the American River in the neighborhood of New York and Sailor Canyon, where the lower part contains numerous imperfect ammonites and shells of *Daonella* and *Monotis*. The basal bed is a closely packed conglomerate of chert and slate, and all the relations observed on the American River Lindgren thinks "point strongly to an unconformity between the Juratrias and the Carboniferous."

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The fossils and the lithology of the Sailor Canyon beds on American River at once suggest the Swearinger formation to any one familiar with the Taylorsville region, but this may be deceptive. Professor Hyatt, who has made a thorough study of the fossils from both localities, remarks[a] that "the entirely distinct species of the two localities, even in the genera *Monotis* and *Daonella*, show that there were two distinct faunal areas, and that there could have been no communication between them during the time of the deposition of the *Monotis* and *Daonella* beds, even if it is admitted that they were contemporaneous in deposition, an opinion which can not be maintained by any facts now known."

MILTON FORMATION.

Turner describes the formation as made up "largely of tuffs, all of which, being evenly stratified, present the appearance of having been laid down in water. These beds contain igneous fragmental (pyroclastic) material of the augitic greenstone series, quartzite, fine red slates, a little marble, and a variegated breccia or conglomerate." The limestone contains garnet and wollastonite and the sandy sediments brown mica developed under the metamorphosing influence of the adjacent granitic intrusions. The Milton formation, Turner states, is distinctly later in age than the siliceous slates (Sailor Canyon) and are probably Jurassic. A comparison with the Taylorsville section suggests that they may be the equivalent of the Trail formation, which is of fresh-water origin and contains much pyroclastic material with other sediments and few fossils.

In the northwest portion of the Truckee quadrangle masses of diabase and diabase porphyry intercalated in the slates and tuffaceous rocks are of frequent occurrence, and Lindgren suggests that they may be the Milton formation.

On the general geologic map of the Lassen Peak region and the northern end of the Sierra Nevada the Sailor Canyon beds are mapped as Triassic and the Milton as Jurassic. Lindgren and Turner pointed out that these rocks are much less compressed than those of Paleozoic age. These Mesozoic rocks dip eastward and appear to be conformable throughout, but rest with marked unconformity upon the Carboniferous rocks.

A short distance east of the area covered by the general map (Pl. I), in western Nevada, are a number of localities at which fossiliferous Triassic and Jurassic strata have been found. The most important Triassic areas are a few miles southeast of Dayton, near Volcano, 30 miles northeast of Walker Lake, at New Pass in the Desatoya Mountains, and especially at Star Peak near Humboldt, a locality made famous by the work of the Fortieth Parallel

[a] Bull. Geol. Soc. America vol. 5, 1894, p. 399.

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Survey. At all of these localities the fossils indicate, according to Professor Hyatt[a] and James P. Smith,[b] a horizon lower than the Hosselkus limestone, about the position of the Pit shales so well exposed in the Redding quadrangle. Lindgren has shown[c] that in northeast Oregon and the adjoining portion of Idaho the Triassic, like that of the Taylorsville and Redding regions, is well developed, suggesting connection with the great masses of British Columbia. At Soda Springs, Idaho, about 100 miles north of Ogden, a still lower horizon of Triassic occurs. It is the oldest known in the Nevada basin region. This basin contains also Jurassic strata. As shown by Hyatt, the fauna of the Hardgrave formation of Taylorsville occurs at Volcano, 30 miles east of Walker Lake in Nevada, and at Bear Creek in the Blue Mountains of eastern Oregon, and he asserts[d] that "it is obvious that there was no barrier between these three littoral faunas at the time of the deposition of the upper Lias of Taylorsville and that the three basins were contemporaneous and connected."

RELATION OF THE TAYLORSVILLE JURASSIC TO THE MARIPOSA.

The latest conclusion of Professor Hyatt concerning the relative age of the Jura-Triassic rocks of the Sierra Nevada[e] places the Hinchman formation about the middle of the upper Jurassic next older than the Mariposa formation that lies toward the base on the west slope of the Sierra Nevada. He remarks the distinctness of their faunas. The areal relation of the two formations at their nearest approach is shown on the general map, Pl. I. The fauna of the Foreman beds had not been discovered when Professor Hyatt wrote, and it seems very probable that a thorough study of it by a paleontologist in the field may bring the Foreman beds, the latest Jurassic of the Taylorsville region, and the Mariposa still closer together.

The Mariposa formation outcrops on the western slope near the foot of the Sierra in several long, narrow areas approximately parallel to the range. To the northwest of Mariposa, one belt of exposures ends near Folsom and the other near Colfax. Farther in the same direction, near Oroville, some black slates containing a remarkable flora have been called Monte de Oro formation by Turner.[f] Their lithologic similarity to the Mariposa is striking and their flora is thought by the paleobotanists to indicate about the same horizon.

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[a] Bull. Geol. Soc. America, vol. 5, 1894, p. 400.

[b] Jour. Geology, vol. 6, 1898, p. 778.

[c] Science, new ser., vol 13, 1901, p. 270.

[d] Op. cit., p. 401.

[e] Op. cit., pp. 412-413.

[f] Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, p. 548. A fuller account of this formation is in course of publication by the present writer in the Bulletin of the Geological Society of America, vol. 19.

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In these plant beds, however, some invertebrate fossils have been recently discovered by James Storrs and they throw new light on the age. Concerning Storrs's collection T. W. Stanton reports (February 3, 1908) as follows:

About a year ago, in reporting on another collection obtained by Mr. Storrs from these beds, I expressed the opinion that they are Jurassic, and older than the Mariposa beds. The fossils now under examination add several species to the previous list, although I am still unable to assign them to described species, and they do not therefore afford a good basis for correlation with well-established horizons. Perhaps the most important addition is the form doubtfully referred to *Aucella*. It is represented by one fairly good valve and a fragment of another which might belong to either *A. piochi* of the Knoxville or to *A. erringtoni* of the Mariposa as far as can be determined from the features preserved. Unfortunately there is no right valve in the collection, and the generic reference is not positive. If it is really an *Aucella*, the age of the beds is either Mariposa or Knoxville, more likely the former. The general character of the other forms is suggestive of the older faunas of the Taylorsville region, but it must be admitted that there is no definite evidence of this.

The following list mentions the forms distinguished:

Ostrea sp.

Pecten. Two or three species.

Aucella? Imperfect specimens with the form of *A. piochi* or *A. erringtoni*.

Modiola sp.

Trigonia sp.

Cardium? sp. This is an abundant species that in a previous report was thought to be an aviculoid shell and doubtfully referred to *Eumicrotis*. The specimens of the present collection are somewhat better preserved, but the generic reference is still doubtful.

Belemnites sp. Several fragments.

SUPPOSED MARIPOSA IN NEVADA.

In western Nevada, according to King,[a] a thickness of probably 4,000 feet of fine-grained argillaceous slates overlies the Jurassic limestone, and he says: "It is quite clear that these upper Jurassic slates are to be correlated with the similar rocks in California." Later researches have not yet thrown definite light upon the above correlation except that it now seems possible and perhaps probable that the slates of western Nevada may be equivalent, at least in part, to the Foreman beds of the Taylorsville region.

TERTIARY.

AURIFEROUS GRAVELS.

GENERAL STATEMENT.

The auriferous gravels outlined in the maps of the Taylorsville region are deposits of an ancient system of drainage, in Tertiary time, very unlike that of the same region to-day. The principal ancient stream, Jura River, had its source in the high Sierra summits, possibly west of the main crest, in the neighborhood of English Moun-

[a] Systematic geology: U. S. Geol. Explor. 40th Par., vol. 1, 1878, p. 295.

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tain, as shown in Pl. I, and flowed in general a little west of north, by the Cascade mine, across the Downieville quadrangle and the Mount Jura divide, in the Taylorsville region, to the northern end of the Sierra Nevada, beyond Indian Valley, where it entered a larger body of water and formed the main mass of auriferous gravel, one of the most extensive deposits of its kind in California.

AURIFEROUS GRAVELS OF JURA RIVER CHANNEL.

Mount Jura divide.—The divide extending northeast from Mount Jura toward Kettle Rock has four areas of auriferous gravels, as shown in Pl. III, and preserves a cross section of the ancient valley once occupied by Jura River. The two largest of these masses have been mined at Taylor and Hull diggings and range in altitude from 5,300 to 5,600 feet. One of the smaller areas near the west side extends down to 5,100 feet, but this may be due in part to a landslide; the other lies at an altitude of 6,000 feet on the east side of the valley. In all probability these four areas were once connected, forming a continuous mass for approximately 5 miles along the divide.

Taylor diggings.—Taylor diggings, a mile northeast of the summit of Mount Jura, were operated years ago by a ditch from Taylor Lake, near Kettle Rock, and expose about 100 feet of gravel, at the bottom of which lies a bed of impure lignitic coal about 5 feet in thickness. Prospect tunnels have been run into this bed for a short distance to the west and south and about a ton of coaly material removed and tried for blacksmithing. The coaly material lies on Jurassic bed rock and is overlain by gravel, varying in size, but throughout a thickness of 100 feet rarely as much as 6 inches in diameter. The pebbles are chiefly metarhyolite, like the rock so well exposed along the eastern slope of Grizzly Mountains. The remaining pebbles are for the most part granite and basic igneous rocks, some of which are rich in pyroxene.

Hull diggings.—On the Lucky S road is a flat-topped mass of gravel capping the divide and main spur for over 3 miles. At the head of the north fork of Hosselkus Creek, Hull diggings expose about 100 feet of gravel, in the upper portion of which there are 15 feet of fine sand and gravel. The coarser gravel above and below contains pebbles rarely as large as a man's head. Toward the bottom there is much sand and bowlders of metahornblende-andesite porphyry unlike the meta-andesite bed rock, and some of the bowlders are 5 feet in diameter. Whether these bowlders occur sporadically in the sand or form a distinct layer could not be determined for lack of definite exposure. No bowlders occur in the well-exposed upper half of the deposits. Similar bowlders occur along the borders of the exposed areas where the gravel has been removed and has brought

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the bowlders to the surface. Farther southwest toward Taylor diggings a number of granite bowlders occur with the others, and it is evident that all came out of the gravel deposit.

The small mass of gravel on the Lucky S road, 2½ miles east of Hull diggings, is fine and contains many dark pebbles like hornfels. No bowlders were observed. The gravel, although well rounded, differs considerably in composition from that farther west, and it is possible that this deposit belongs to a side stream.

The gravels of the Mount Jura divide contain no pebbles of the Tertiary lavas which lie to the east and northeast. Many pebbles of igneous rocks are present, but they are all of types that belong to the pre-Tertiary bed-rock series.

Peale diggings.—Following up the Jura River deposits south from Taylor and Hull diggings, we come to three flat-topped masses of gravel at an elevation of from 5,500 to 5,800 feet capping the divide between Wards Creek and Little Grizzly Creek, southwest of Genesee Valley. Peale diggings in these masses expose about 100 feet of gravel, in which pebbles of old rhyolite or quartzite like those of Grizzly Mountains are most abundant. There are some of darker igneous rock and a few of granite. Pebbles 6 to 10 inches in diameter are common, but bowlders as large as 2 feet in diameter are rare.

In the gravel bars of the present streams of the Taylorsville region, and in fact along all streams with fairly strong grade, it may be observed that the somewhat flattened pebbles instead of lying horizontal are generally inclined so that they lean downstream, and, like shingles of a roof, overlap in that direction. Their upper surfaces slope upstream. This is their position of greatest stability against stream erosion and shows the direction of flow in the stream making the deposits.

At the Peale diggings most of the pebbles are approximately spherical, but a few are somewhat flattened and generally slope southward, showing that the stream came from that direction. The fact that the pebbles are largely of quartz porphyry, like that of Grizzly Mountains, from which the stream came, points to the same conclusion.

Cascade mine to Mohawk Valley.—The facts of the country south of the fortieth parallel are drawn largely from the publications of Turner and Lindgren. In the Downieville folio, page 4, Turner has traced the deposits of the ancient stream we are following from 2 miles southeast of Tower Rock southward, by way of the Cascade mine, Lava Peak, and Mohawk Valley, to Haskell Peak and beyond in the crest of the main divide between Mohawk Creek of Feather River and North Fork of Yuba River.

At the Cascade mine sandy layers are interstratified with gravel, and the total thickness of the deposits is 325 feet, at an elevation of

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about 6,000 feet. There are large granite bowlders in the gravel and the bed rock belongs to the auriferous slate series, cut by numerous dikes. The occurrence of granite bowlders to the north of their source, though but a short distance, Turner thinks may be regarded as evidence that the stream flowed to the north. The Cascade mine gravel lies on the edge of a great mass of andesitic breccia, beneath which it extends southward, to reappear on the slopes of Little Long Valley Creek at an altitude ranging from 6,000 down to 5,000 feet; and a little farther south at Cedar Creek, on the border of Mohawk Valley, the gravels appear to reach a somewhat lower level.

From Peale diggings to Mohawk Valley the deposits "are similar in being made up of gravel and coarse sand with very little fine sediment," and Turner remarks, "this may be taken as evidence that the river bed had a higher grade than the river beds of the southwesterly system in the western half of the Downieville quadrangle."

Along Haskell Peak escarpment.—South of Mohawk Valley the ancient gravels of Jura River appear in patches at an altitude of about 7,000 feet on the edge of a plateau-like ridge running northwest of Haskell Peak. Here the gravels are overlain by rhyolite, which is in turn locally overlain by andesite. The gravels contain a great variety of pebbles. Turner mentions "contact metamorphic schist, granite porphyry, altered glassy andesite (?) showing flow structure, an altered holocrystalline basalt, a variegated breccia (red and green) made up of microlitic fragments of lava, and a red fine-grained tuff." The last two are very similar to some of the tuffs of the Milton formation and he suggests that they probably came from Chips Hill, farther south, where the Milton formation lies directly beneath the gravel.

Chips diggings, reversed drainage.—At Chips Hill, 3 miles northeast of Sierra City, where the gravel has been extensively mined, it is overlain by rhyolite, and this in turn is covered by andesitic breccia. The bed rock is at an elevation of 6,500 feet, or about 500 feet lower than the gravel of Haskell Peak, with which Turner thinks it was once connected by a stream flowing north. He considers that a great displacement has taken place between Mohawk Valley and Haskell Peak, with differential change of level on the western side of the fault that reversed the drainage from north to south.

Three miles southeast of Sierra City, at an elevation of 6,500 feet, is a trace of river gravel on the edge of a flow of rhyolite that has come down from the crest southeast of English Mountain, which Turner regards as the head of the ancient gravel stream that flowed north by Mount Jura.

Question as to head of Jura River.—The course of the stream beyond Haskell Peak is a matter of doubt. As given above it enters the

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Downieville quadrangle near Milton, coming from the Colfax quadrangle, where Lindgren has studied the ancient streams in detail. He refers to a strongly marked depression beginning in the vicinity of Fordyce dam and extending northwesterly in the direction of the Milton-Meadow Lake channel, which he describes, and he concludes from the bed-rock elevations that it turned westward in the vicinity of Milton, where it was joined by "a tributary coming down from the vicinity of Haskell Peak," and remarks,[a] "the high bed-rock ridges near Haskell Peak, the northern side of which has been examined by Mr. H. W. Turner, preclude, except by assuming very large subsequent disturbances, any supposition that the channel could have flowed northward from Milton." It is evident that the difficulty in the way of accepting Turner's view as to the source of Jura River would be removed if it could be made to appear probable that the Milton region, including Chips Hill, had subsided with reference to Haskell Peak and reversed the slope. The argument in favor of this view to be drawn from the relation of the present divide to the main ridge will be considered presently. Attention will be given first to the light thrown on the question by the distribution of the gravels.

The large deposits of gravel at Haskell Peak give positive evidence of a good-sized stream. The gravel, composed, as Turner has shown, of a great variety of rocks, rests directly on granodiorite and must have been brought from some distance. At that time Haskell Peak did not exist. It is made of lavas all of which are younger than the auriferous gravels and overlie them, so that Haskell Peak can not be considered the source of the ancient gravel stream. Whatever the direction of flow of the gravel stream at Haskell Peak, except directly on the line of the crest, it must since have experienced a reversal of drainage slope on the approaching side. The definite knowledge of Jura River and its deposits from Mohawk Valley north demonstrates that it is not the north-slope drainage of Mount Haskell that has been reversed, and points to the south slope as the one reversed.

For 2 miles northwest of Haskell Peak the ancient gravel stream bed follows the divide to a point where the crest is offset to the west. Here the gravel ends. Leaving the divide and following the stream course northwest no gravel is seen for nearly 10 miles, until it appears on Cedar Creek beyond Mohawk Valley. From that point to Mount Jura divide the channel is easily traced.

If now we return to Haskell Peak and try to follow the stream course along the crest to the southeast no trace of it appears, although the crest is bare and well fitted with local lava capping which might reasonably be expected to preserve the gravel in place. It appears most probable, from the absence of gravel on the divide, that the channel lay farther west, more nearly in the direction of the general course

[a] Two Neocene rivers of California: Bull. Geol. Soc. America, vol. 4, 1893, p. 276.

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of the stream. The known gravel masses which lie beyond Haskell Peak most nearly in the general course of the ancient stream are those of Chips Hill in line with that on the divide north of Milton, suggesting their source for the Haskell Peak gravels.

Drainage suggested by rhyolite flow.—There is a suggestion of continuous drainage from Meadow Lake to Haskell Peak in the distribution of the rhyolite flows which followed the watercourses, but the suggestion may be misleading, for the rhyolite appears to have come from several sources. The flow from near Meadow Lake, outlined by Lindgren, may have continued as far northwest as Chips Hill, but the large mass farther north, as pointed out by Turner, probably originated in Haskell Peak.

If the drainage at the time of the rhyolite eruption was westward in the vicinity of Milton, and the supply of lava sufficiently large, a westward turn of the rhyolite stream would be expected. Such a turn is suggested in Findley Peak, and others may have been washed away. It is possible, too, that the rhyolite north of Middle Fork of the Yuba came from Haskell Peak. Whatever may have been the course of drainage during the gravel period or at the time of the effusion of the rhyolite, there can be no question that the streams of andesite from the eastward followed essentially the present system of drainage through a gap in the line of the main crest represented by Sierra Buttes.

Suggestion of double crest.—It is important to note that the topography of the region is exceptional in that there are two crests. The main crest between Mount Elwell and Castle Peak passes through Sierra Buttes, Findley Peak, and English Mountain to Meadow Lake, but this crest is not the present divide. The divide curves eastward through Haskell Peak and Webber Peak to near Meadow Lake, as if following the summit of what may be a small fault block east of the main crest between Sierra Buttes and Sierra Valley.

Fan-shaped drainage of the Milton region.—The drainage of the area in question is peculiar in that it is open fan-shaped. Both North Fork and Middle Fork of Yuba River head in this region. Their head branches converge toward Milton, where the two master streams turn west and within 3 miles of each other cut across the line of the old crest south of Sierra Buttes and then diverge down the western slope of the range. The peculiar constriction of these stream courses near their head can not be due to the relatively hard rocks of Sierra Buttes, for such rocks do not appear on the Middle Fork.

Present divide.—The highest points of the Haskell Peak divide are chiefly of volcanic rocks, which are later than the gravels, while the main ridge about Sierra Buttes is made entirely of bed-rock series. It is possible that during the gravel period the main ridge was the divide

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giving birth to the drainage as outlined by Turner, but at the close of the gravel period, when the Mohawk Valley and Sierra Valley region sank 2,000 feet, the Milton region may also have gone down 500 feet and established a new divide through Haskell Peak.

MAIN MASS OF AURIFEROUS GRAVEL.

The main mass of auriferous gravel is spread in irregular patches over an area about 20 miles in length and 9 miles in breadth, with the greatest dimension parallel to the crest of the Sierra Nevada, on which it lies. Its western portion, in the Moonlight region, will be considered first and then, in order, the northern, eastern, and southern portions.

The Moonlight region.—Moonlight lies 12 miles north of Taylorsville, at the head of Surprise Creek. The divide east of Moonlight, ranging in altitude from 5,600 to 7,000 feet, is drained by the west fork of Lights Creek and affords the most extensive section of auriferous gravels in the region. The total thickness is over 1,000 feet. The lower 400 feet is chiefly sand and the upper 600 feet gravel or conglomerate, which is especially remarkable on account of its lithification.

The conglomerate is sometimes so firmly cemented that when the rock is broken the fracture passes through instead of around the pebbles. This feature gives to the conglomerate an aspect of greater age than the loose gravel possesses. Some of the conglomerate is fine, with pebbles of quartz of various colors and many pebbles of old andesitic rocks, like those of the county-line ridge, to the north. The paste is greenish and, as the microscope shows, is composed largely of igneous material. The smooth round pebbles of the coarse conglomerate are occasionally faulted. Many pebbles are a foot in diameter, and rarely they are 2½ feet, but they average about an inch. A few beds of sand occur in the conglomerate, and when fine they generally contain fossil leaves, of which collections were made. The conglomerate and interbedded sandstone apparently strike N. 10° E. and dip 20° NW. The steep slope east of Moonlight is so covered with faulted landslide blocks that it is difficult to find the rock in place, but the whole succession of conglomeratic beds appears conformable and not less than 600 feet in thickness.

The sandstone beneath the gravel for 100 feet is fairly well cemented and some of it is light gray, like tuff, but the microscope shows it to be made up of angular particles of quartz and some plagioclase with much argillaceous matter and no definite volcanic fragments. Below this the material is softer and landslides abundant. Exposures are few, and the sand of the lower portion of the deposit is arkose. The rocks, too, beneath the sand are largely disintegrated. Traces of leaves occur at many places, and the upper part where firmly cemented makes a rough ridge with steep cliff face to the east. The thick mass of the Moonlight region extends north across the divide to the head of Wil-

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lards Creek, where it expands into a much larger area, to be noted presently.

South end of Mountain Meadows.—At the southeast head of Mountain Meadows is a body of well-rounded gravel which covers the broad and low divide between Mountain Meadows and Cooks Canyon. The gravel is not cemented, lies flat as deposited, and looks younger than that of the conglomerate east of Moonlight. It represents the unmodified bed of the western branch of the ancient Jura River. The gravel is not very coarse and bowlders are not common. Where mined, it is underlain by sand, and the whole mass is not over 20 feet in thickness. In one mine only 5 feet of gravel was exposed overlying 2½ feet of gray and reddish sand. Upon both sides it is limited by ancient igneous rocks. To the southeast it has been washed away, and thus its connection with Moonlight has been severed. To the northwest it passes beneath the alluvium of Mountain Meadows and does not reappear until the northern end of the meadows is reached at the Narrows. The slope east of Mountain Meadows is generally free from gravel and is formed of ancient volcanics capped here and there by later flows of lava which have not been mapped.

North end of Mountain Meadows.—The Red Bluff-Susanville road is on gravel from the north end of Mountain Meadows across the divide to near Stocktons, a distance of about 10 miles. West of the summit the streams (dry in summer) which enter the meadows from the southeast at Nanney and Browns afford sections of about 500 feet of gravel capped on the crest by lava and tuff. The gravel has a large proportion of siliceous pebbles. Many are of black chert, with others of old sandstone and conglomerate and a few of older igneous rocks. In this regard as well as in their general lack of cementation they are strongly contrasted with the deposits of older gravel on the slope east of Moonlight. These gravels south of Browns, so clearly capped by lava and tuff, are underlain by sand, which gives rise to many landslides, some of whose basins still contain swamps or ponds. This pitted surface has the aspect of a moraine, but contains no bowlders, and passes into protected portions which are not only free from landslides, but pass beneath the capping layer of andesite tuff. Half a mile southeast of Nanney was found a smooth round pebble of fossiliferous sandstone like that of Hinchman Ravine on Mount Jura. Near the summit of the gravel pebbles of modern lava become abundant, but no definite horizon was observed at which the pebbles of modern lavas begin to appear.

Generally the gravel about Mountain Meadows is not cemented, but a rather striking exception to the rule occurs one-fourth mile northwest of Browns, where the cemented sand and gravel rich in quartz forms a low divide and is overlain by loose gravel, which is finally capped to the northwest by volcanics. It seems probable that the

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cementation of the gravel in this case may be due to the intrusion of the andesite which forms the bluff opposite Nanney.

Willards Creek district.—On the slopes of Willards Creek the auriferous gravels are exposed to a thickness of over 500 feet, but the sediments are not so firmly cemented as those east of Moonlight and at the head of Gold Run. The gravels exposed contain numerous pebbles of fresh lava with those of black chert, sandstone, and other siliceous material, which appear to have been derived from earlier gravels by erosion. One of the pebbles of gray sandstone contained a characteristic *Rhynchonella* of the Mormon formation of Mount Jura near Taylorsville, and indicates clearly its source. The following section was observed 1½ miles southeast of the road summit:

Section near road summit, Willards Creek district.

	Feet.
Andesitic volcanic breccia	20
Gravel containing many lava pebbles with older ones of chert, etc	75
Sandstone with a little fine conglomerate and light-colored beds of fine rhyolitic tuff	90

No satisfactory exposure was obtained of the material underlying the rhyolitic tuff.

The tuff is composed largely of light-brown amorphous dust, splinters of clear glass with fragments of clear glass pumice, and angular grains of quartz, feldspar, augite, and hornblende. It is decidedly cross-bedded and appears to dip gently to the northeast.

A chemical analysis of this rhyolitic tuff (p. 92) shows that it is apparently identical with the rhyolitic tuff which caps the earlier gravels at various places on the western slope of the Sierra Nevada. Unfortunately, on Willards Creek the part of the section below the rhyolitic tuff was not found exposed.

Head of Gold Run.—Gravel occurs along the Taylorsville road most of the way down Gold Run. Near its head west of the road where firmly cemented the conglomerate has a thickness of over 350 feet, dips gently to the northeast, and forms prominent cliffs. At this point the conglomerate varies in the size of the pebbles, but is rarely coarse. Some of the pebbles are crushed and faulted in a way to indicate great strain. These effects were observed only in the conglomerate near the crest of the range, from which considerable material may have been removed by erosion. Many of the pebbles are of old volcanic rocks like those noted in the gravels east of Moonlight. The interbedded lenses of fine sediment occasionally contain fossil leaves, of which an excellent series of specimens were collected by James Storrs in 1904. They were obtained about three-fourths of a mile northwest of the road summit and 350 feet below it, on a branch of the west fork of Gold Run. Dikelike bodies of hornblende andes-

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ite cut the conglomerate gravels at this point, and their intrusion may have had something to do with the induration of the gravel mass.

Diamond Mountain gravel.—On the Sierra crest, a few miles southeast of the Lights Canyon road summit, there are two high points, both composed of andesitic breccia. The west one is commonly known as Red Mountain on account of the colored tuff, while the other, about a mile to the northeast, is called Diamond Mountain. Between them is a ridge of gravel which is overlain by the volcanic breccias of the two peaks. Near Red Mountain the gravel of this ridge is composed largely of quartz, chert, and old sedimentary as well as igneous rocks. Farther east as the ridge rises lava pebbles come in, and near the top the pebbles are almost wholly of lava. The contrast between the earlier quartzose gravel and the later directly overlying gravel of lava fragments is striking. The gravel contains occasional bowlders, some of which are 12 feet in diameter and entirely out of accord with the associated well-rounded gravel. One bowlder and several large pebbles were found with striæ, but no definite glacial moraines were distinguished.

Southeast of Diamond Mountain a prominent ridge of gravel forms the crest of the Sierra for several miles at an altitude of over 7,000 feet, overlooking the bold escarpment facing Honey Lake Valley. The gravel of this prominent crest ridge is about 300 feet in thickness and rests on the granite which outcrops on the eastern slope. The gravel is coarse and chiefly of andesitic fragments on the surface, but near the bottom is finer, though the lower half of the mass contains most of the granite bowlders strewn on the eastern slopes. The ridge is separated from Diamond Mountain by a gap from which the gravel has been removed. A small pond occurs in the gap, and a flow of basalt with flow structure rising to the northeast forms a cliff facing in the same way as if the lava flow came from that direction. Similar basalt hangs on the granite slope a mile to the southeast. A small gravel scarp near the pond suggests faulting.

Gravel has been mined to a very limited extent along the eastern base of the Sierra, a short distance south of Gold Run, 4 miles from Susanville, but no large body of gravel is exposed at that point. If it ever extended so far east, it has probably been covered by the later lavas and lake deposits of that region.

Diamond Mountain shore terraces.—Shore terraces are well developed about Diamond Mountain, as though it were an insular mass against which the waves beat and carved out a shore line. As shown in fig. 9, Diamond Mountain has five spurs running in various directions. The summit of the mountain is (1) andesitic breccia, about 300 feet in thickness. On each spur the breccia is limited by a more or less clearly defined shore cliff, beyond which is a mass of (2) gravel composed almost wholly of well-rounded lava fragments.

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Beyond the lava gravel (2) on most of the spurs at a lower level comes (3) the gravel in which pebbles of Tertiary lavas are rare or absent and pebbles of quartzose rocks are most abundant. Their general relations in a vertical section are shown in fig. 10, where the numbers have the same significance. The total thickness of the gravel is less than 300 feet. Granite bowlders appear to be most abundant on the lower half of the gravel. Farther southeast along the crest under the thick mass of basalt flows, forming Thompson Peak, there is no gravel separating it from the granitic rock. On the contact the basalt includes a residual bowlder of diorite, showing that the basalt flowed over a surface long exposed to disintegration.

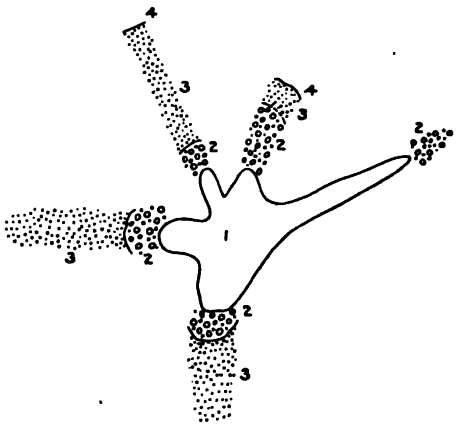

FIG. 9.—Sketch plan of Diamond Mountain, showing shore terraces on spurs. 1, Andesitic breccia forming summit; 2, gravel of lava pebbles on shore terraces on spurs; 3, gravel rich in quartz pebbles; 4, granodiorite.

Lone Rock and Kettle Rock regions.—Southwest of Diamond Mountain, in the flat country drained by the headwaters of Indian Creek, the gravels are widely distributed in a heavy body, although much of it has been removed by erosion. The east border laps over upon the granite without any lava capping and extends south, sending a branch to the forks of Indian Creek, where it ends at an elevation of about 1,000 feet below the main crest of the gravel ridge. West

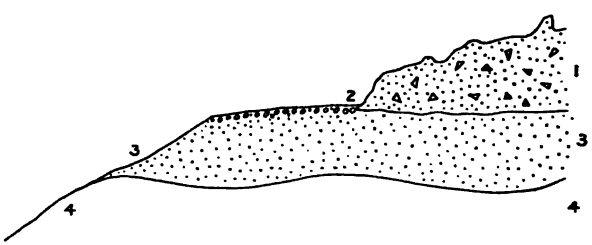

FIG. 10.—Generalized section of spur of Diamond Mountain. 1, Andesitic breccia; 2, gravel of lava pebbles; 3, gravels rich in quartz pebbles and sand below; 4, granodiorite.

of Lone Rock, on the branches of the south fork of Lights Creek, the gravel was not cemented and has been largely removed, leaving on the lower slopes but a thin coating on the arkose sands, which contain occasional well-rounded quartz pebbles to show that they are not residual but recomposed. Farther south it caps the broad divide rising toward Kettle Rock, and above the Lucky S mine reaches

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an altitude of over 7,000 feet. Several hundred feet of gravel occur here. The lower part is fine, with many pebbles of quartz and siliceous rocks, and the upper part, associated with the volcanic breccia, is composed chiefly of andesitic fragments. The earlier gravels near the Lucky S mine were once connected with those of a few miles southward on the Mount Jura divide, but the later gravels of lava pebbles present above the Lucky S mine appear to be absent on the Mount Jura divide.

ISOLATED MASSES OF GRAVELS NORTHEAST OF MOHAWK VALLEY.

This country forms the eastern slope of Jura River and is somewhat remarkable for the paucity of its gravels. The principal body found in this region is near Mapes, on Squaw Creek, 5 miles northeast of Chase's, where a knoll on the meadow border is made up of cobblestones and pebbles of granite and dark shaly rock, with many of lava. Though of small extent it is a veritable washed gravel, and must once have underlain an adjacent mass of lava several hundred feet in thickness. Whether the gravel rests directly on the granodiorite or is separated from it by a thin sheet of volcanic rocks was not definitely determined.

Traces of gravel and bowlders were found on the west side of the crest opposite Milford, but similar pebbles occur in the associated tuff, and they may have been liberated by weathering. By a small area of altered rocks inclosed in the granodiorite, 3 miles southwest of Clark's dairy, there is a small mass of quartz gravel locally developed, which may represent a small stream extending to the margin of the delta gravel only a few miles to the northwest.

A few pebbles of quartzose rocks were found near Chase's on Red Clover Creek, but no definite body of gravel was seen in place. However, it is not only possible but probable that a stream passed near there, for on the north slope of Mount Ingalls is a mass of well-rounded coarse gravel of lava fragments deposited during the volcanic period, but most likely representing a descendant of a stream of the prevolcanic period.

The contact of the gently rolling platform of granodiorite and the overlying sheet of volcanic rocks was examined at many points about the heads of Squaw and Last Chance creeks without finding a trace of gravel, and it is certain that the great sheet of estuarine gravel, which at Diamond Mountain lies between the sheet of volcanic rocks and the granodiorite, does not extend south of the latitude of Kettle Rock.

Along the fortieth parallel east of Red Clover Creek granodiorite forms a broad platform gently inclined to the northwest. It is covered throughout most of the area by a sheet of volcanic rocks whose thickness is only a few hundred feet. The thin cover it makes for

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the granodiorite is especially well exposed along the eastern escarpment, where it appears only on the crest. The escarpment is of granodiorite.

CLASSIFICATION OF THE AURIFEROUS GRAVELS.

The early investigations of the Geological Survey of California under J. D. Whitney proved the fluviatile origin of the gravels, but it remained for the later workers, especially Ross E. Browne, H. W. Turner, and Waldemar Lindgren, to work out their classification. The latest expression on the subject is by Lindgren,[a] who states that in the principal broad Neocene river valleys one may generally distinguish the following formations:

A. Antevolcanic deposits.....	1. The deep gravels.
	2. The bench gravels.
B. Volcanic and intervolcanic deposits.	3. The rhyolitic tuffs.
	4. The gravels of the rhyolitic period.
	5. The gravels of the intervolcanic erosion period.
	6. The andesitic tuffs and tuffaceous breccias.

For various reasons the gravel deposits where thickest, east of Moonlight and at the head of Willards Creek, are not worked, so that complete and detailed sections are nowhere available. The lower portion of the mass especially is affected by landslides, and outcrops are few. As a whole the deposits of the Taylorsville region included under the general term auriferous gravels may be considered under the following headings:

EARLIER DEPOSITS (PREVOLCANIC).

Arkose sands.—At every point where the bottom portion of the main mass is exposed it is found to be composed of sand, and the greater part, especially the lower, is often decidedly arkose, so much so that in some of the mines it was difficult to tell whether the material was simply disintegrated granodiorite in place or recomposed. In most cases careful search ultimately brought to light a few small but smooth round quartz pebbles to prove it arkose. Gravel beds in this portion are rare. In some cases carbonaceous clay beds, amounting even to impure coal, occur, but it is not certain that they underlie the main mass, though the sand is believed to underlie the whole with a variable thickness, and a local maximum of not less than 500 feet. Some of it is lithified, forming sandstone.

When we turn to the river channel some distance above where it joins the main deposits, as, for example, at Peale diggings and farther up the stream, the fine beds at the bottom have disappeared. It is to be expected, of course, that the main mass in general is older than that in the channel, which is ever moving downstream to join the delta.

[a] Jour. Geology, vol. 4, 1896, p. 881.

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The prevolcanic gravels.—These gravels usually contain more or less pebbles of white quartz with others prevailingly quartzose, and all are derived from the bed-rock series, among which there are many igneous rocks, but no Tertiary lavas. The material ranges in size from occasional sand streaks to scattered bowlders up to 12 feet through, but the greater number of the pebbles are from 1 to 4 inches in diameter. Locally they are cemented so as to form conglomerate. The gravels of the Jura River bed throughout its whole course, as well as the bulk of the gravels of the delta, belong to this horizon. It has a maximum thickness of over 500 feet, and near its base contains fossil leaves.

It has not been found possible at any point I have had an opportunity to examine along the course of Jura River to distinguish the deep gravels and the bench gravels described by Lindgren. The great bulk of the stream gravels in the broad channel are undoubtedly bench gravels, but the presence of the deep gravels could not be clearly demonstrated. More extensive mining may bring them to light. However this may be, the equivalents of both deep gravels and bench gravels most likely occur in the main mass, but have not yet been distinguished.

LATER DEPOSITS (INTERVOLCANIC).

Rhyolitic tuff.—In the region of Willards Creek rhyolitic tuff was found interbedded with sandstone between masses of conglomerate, and it belongs in the succession of gravels before the eruption of the volcanic breccia. There are several beds of tuff grading into sandstone which are very similar to the rhyolitic tuffs which Lindgren and Turner have described as overlying the bench gravels in the Sierra Nevada south of the Taylorsville region. Rhyolite flows occur at Haskell Peak and beyond, overlying the gravels to the head of Jura River, and are themselves overlain by flows of andesite breccia, but both kinds of flows are generally absent from the ancient river channel north of the fortieth parallel until the main mass is reached in the vicinity of the present crest. Chemical analyses of the rhyolite tuffs farther south are not available for comparison, but Lindgren, who has kindly examined the slides and specimens from Willards Creek, recognizes them as being practically identical with the rhyolite tuff to which he refers.

Intervolcanic gravels.—Overlying the rhyolitic tuff and sandstone on Willards Creek is a mass of gravel containing a considerable proportion of lava pebbles, and these increase in amount upward through a thickness of about 75 feet. These were found at only one place, and were not studied in great detail at the time, but they appear to lie conformably between the andesitic breccia and rhyolitic tuff and find their equivalents most likely in those of the rhyolitic period and intervolcanic-erosion period of Lindgren.

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Volcanic flows, chiefly andesitic breccia.—This material is mainly of hornblende and hypersthene andesite, often in the form of breccia, such as filled the broad valleys and covered the rhyolite flows and auriferous gravels at many points. Their source in the Taylorsville region is fairly well marked at Red Mountain, near Diamond Mountain, and a few miles farther northwest on the crest, and by their extrusion over the submerged end of the Sierra Nevada the bottom became very irregular. As eruptions progressed the water became more shallow, with islands along the summit.

Shore gravel.—The islands along the crest are bordered by beach platforms paved with coarse gravel and cobblestones of andesite, with a few of basalt derived directly from the adjacent shore. Their lower portions locally join the intervolcanic gravels, but their relations could not be fully determined. The prevolcanic gravels at Moonlight and the head of Willards Creek, as already pointed out, have a decided dip of from 15° to 20°, which appears to indicate tilting after deposition; but as clearly bedded andesitic tuff associated with the volcanic breccia shows the same inclination, it appears that the tilting took place in the final movement after all the gravels were deposited, possibly with essential conformability throughout.

IONE FORMATION.

The Ione formation, made up chiefly of sand and gravels, lies along the western base of the Sierra Nevada in the Sacramento Valley, where Lindgren[a] has found that it contains Miocene shells, and with Turner[b] has shown that it was deposited synchronously with the older auriferous gravels. The Ione formation is extensively developed in the eastern part of Shasta County, from Cow Creek to Kosk Creek, beyond the great bend of Pit River, and contains fossil leaves and local traces of coal. The strata dip easterly beneath the great mass of Tertiary lavas about Lassen Peak, and are believed to represent the same geologic horizon, and possibly are connected with the great mass of auriferous gravels which disappear beneath the same lavas at the north end of Mountain Meadows. This correlation is practically demonstrated by a comparison of their floras.

FLORA OF THE PREVOLCANIC GRAVELS.

The only fossils found were in the earlier auriferous gravels, and collections were made at two localities—one near the eastern end of Moonlight on the slope toward the west fork of Lights Creek, at an elevation of about 6,000 feet, the other three-fourths of a mile north of the road summit between Taylorsville and Susanville, at an elevation of 6,000 feet on the slope of Gold Run, and about 7½ miles southwest of Susanville. Fossils were collected years ago from the same

[a] Jour. Geology, vol. 4, 1896, p. 890. [b] Am. Geologist, vol. 15, 1895, p. 373.

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mass of gravel[a] at the head of Mountain Meadows and also three-fourths of a mile north of the Lights Canyon road summit. Plants from both these localities have been tabulated with the later collections for comparison with those from the auriferous gravels of the Sierra Nevada south of the Taylorsville region, as well as those of the Ione formation on Little Cow Creek and Kosk Creek of Shasta County. The earlier collections examined by Professor Lesquereux have been studied by Knowlton, whose determinations are given in the following table, which contains all the forms thus far identified in the Taylorsville region and in the Ione of Shasta County:

Tertiary fossils from Taylorsville region and vicinity.

Name.	Kosk Creek, head, Shasta County.	Kosk Creek, Shasta County.	Little Cow Creek, Shasta County.	North Mountain Meadows, Plumas County.	Moonlight.	7½ miles southwest of Susanville, Lassen County.	Sierra Nevada south of Taylorsville region.
Acer Bendirei Lesq							6
Alnus Kefersteinii Al. Br			+				
Aralia lasseniana Lesq						+	
Aralia Whitneyi Lesq						++	2
Asplenium Wegmanni						+	
Cinnamomum Scheuchzeri or polymorphum, Al. Br				+			
Fagus Antipofii Abich		+					3
Ficus asiminæfolia Lesq			+				5
Ficus microphylla Lesq			+				
Ficus tiliæfolia Al. Br		+					2
Ficus shastensis Lesq			+				4
Juglans Bilinica Ung			+				
Juglans egregia Lesq	+						1 and 2
Juglans rugosa Lesq						+	
Laurus californica Lesq			+		+	+	2 and 6
Laurus salicifolia Lesq						+	6
Laurus grandis Lesq						++	
Leguminosites sp						+	
Magnolia californica Lesq		+					1 and 2
Magnolia Hilgardiana Lesq						+	
Magnolia Inglefieldi Heer						+	
Magnolia lanceolata Lesq						+	2
Myrica Ungeri Heer							6
Oreodaphne litsæformis Lesq						+	
Persea Dilleri Lesq			+			+	4
Persea pseudocarolinensis Lesq		+				+	1 and 2
Phragmites œningensis Al. Br				+		+	
Platanus appendiculata Lesq					+		2 and 4
Platanus dissecta Lesq			+				2 and 6
Populus Zaddachi Heer		+	+		+	+	1, 2, and 4
Pterospermites spectabilis Heer							6
Quercus convexa Lesq		+			+		2 and 3
Quercus distincta Lesq	+						1 and 2
Quercus gigantissimus Kn						+	
Quercus Moorii Lesq						+	
Quercus Olafseni Heer						+	
Quercus Boweniana Lesq					+		2
Quercus n. sp. cf. Q. elænoides					+		2
Rhus metopioides Lesq					+		
Rhus mixta Lesq		+					2
Sabalites californicus Lesq		+					2
Salix californica Lesq					+		2
Sphenopteris Guyottii Lesq	+						
Ulmus californica Lesq		+					1 and 2
Ulmus pseudofulva Lesq					+		2

[a] Eighth Ann. Rept. U. S. Geol. Survey, pt. 1, 1889, p. 420.

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In the final column of the table the particular locality at which the species has been found is indicated by figures. 1 = Chalk Bluff, 2 = Independence Hill, 3 = Table Mountain, 4 = Volcanic Hill, 5 = Rock Corral, and 6 = Monte Cristo mine, Spanish Peak. The fossils from Little Cow Creek and Kosk Creek, Ione formation, are from essentially the same mass. The same is true also of the three localities of the Taylorsville region. For purposes of comparison, therefore, the localities noted in the table may be grouped under three heads; Ione of Shasta County, northern end of the Sierra Nevada, and western slope of the Sierra Nevada.

In the Ione of Shasta County 20 species have been identified, and of these 18 have been recognized in the earlier gravels of the western slope of the Sierra Nevada, leaving no room for doubt that the two formations are for the most part synchronous in origin.

Twenty-seven species have been identified in the gravels of the Taylorsville region, of which 13 occur in the gravels of the western slope of the range, a correspondence which is sufficiently marked to show that the gravels of the two regions are closely related in age.

AGE OF THE PREVOLCANIC AURIFEROUS GRAVELS.

GENERAL STATEMENT.

The age of the auriferous gravels of the Sierra Nevada in California is generally given as late Miocene or Pliocene and is based chiefly on fossil plants and a few animal forms.

In his report on the later collections of fossil plants from the gravels of the Taylorsville region and the earlier collections from the Ione of Shasta County, Knowlton says that they are typical of the auriferous gravels and nothing in the collection suggests an age as old as the Eocene. This statement does not apply to the earlier collection, determined by Lesquereux, which Knowlton regards as of greater age.

The auriferous-gravel period in all probability was a long one, and no considerable part of its flora has yet been connected directly with its contemporaneous marine fauna of the same region. On physiographic and stratigraphic grounds and the general relations of the Sierra Nevada to sedimentation, it has long been supposed by some geologists that the oldest auriferous gravels, the deep gravels of Lindgren, are probably Eocene, but the evidence assigned is problematical rather than positive.

The locality 7½ miles southwest of Susanville, as given in the foregoing table, is essentially the same as the one[a] three-quarters of a mile north of where Light Canyon and the Susanville road cross the summit. The small lens of shale from which the plants were collected in 1886 was exhausted, but another shaly lens near by in the

[a] Eighth Ann. Rept. U. S. Geol. Survey, pt. 1, 1889, p. 420.

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same conglomerate furnished the material collected by James Storrs in 1904. The lenses differ lithologically and the floras are different, but they are reported by Storrs to be in the same mass of conglomerate and therefore of essentially the same age. The earlier collection was regarded by Lesquereux as Eocene.[a]

EOCENE FLORA OF SOUTHWEST OREGON.

While studying the Eocene deposits of the Roseburg, Coos Bay, and Riddles quadrangles in Oregon fossil leaves were found in the same strata with marine shells, affording an opportunity to definitely connect the land flora with its contemporaneous marine fauna.

The following list of 10 species embraces the Eocene plants identified by F. H. Knowlton with more or less certainty from a number of localities within the area noted above:

Magnolia lanceolata Lesq.
Magnolia californica? Lesq.
Laurus californica? Lesq.
Sabalites californicus? Lesq.
Aralia Whitneyi Lesq.
Populus Zaddachi Heer.
Aralia angustiloba? Lesq.
Juglans californica? Lesq.
Ulmus californica Lesq.
Ficus tiliæfolia? Al. Braun.

Among the shells found with or near the fossil leaves Dr. W. H. Dall has recognized over 20 genera, and remarks: "The fossils are Eocene. They contain a number of interesting things, particularly the Orbitolites, which is usually characteristic of the Oligocene on the Atlantic coast and is now for the first time recognizcd from the Pacific coast."

The fossil leaves were found near the southeast border of the Eocene, where shells are not abundant, but a short distance farther northeast they become very abundant locally with such characteristic forms as *Venericardia planicosta* and *Turritella uvasana*, and there is no doubt concerning the Eocene age of the strata containing the fossil leaves.

Of the 10 species of plants identified 7 are somewhat in doubt, but 3, *Magnolia lanceolata*, *Aralia Whitneyi*, and *Populus Zaddachi*, are completely satisfactory. They all occur in the auriferous gravels of Independence Hill, on the western slope of the Sierra Nevada, as well as on the summit of the northern end of the range, 7½ miles southwest of Susanville. The last species occurs at many other localities, among which may be mentioned the Ione formation of Kosk Creek and Little Cow Creek of Shasta County and the auriferous gravels of Moonlight, Chalk Bluff, and Volcanic Hill.

Eight of the 10 species reported from the Eocene of Oregon occur, according to Lindgren, in the bench gravels of Independence Hill, in California. It seems probable, therefore, that not only the "deep gravels," but also the "bench gravels," both of which belong to the prevolcanic gravels, may be of Eocene age.[b]

[a] Proc. U. S. Nat. Mus., 1888, vol. 11, p. 28.
[b] Proc. Washington Acad. Sci., vol. 8, 1907, pp. 405–406.

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TOPOGRAPHY OF THE AURIFEROUS-GRAVEL PERIOD.

The two divides.—The drainage of the Taylorsville region during the auriferous-gravel period clearly supports the view that the Sierra Nevada was then a conspicuous range of mountains with two divides at the north end separated by a longitudinal valley draining to the north. The first or main crest represents the continuation of the great divide of the range northwest from Castle Peak by Sierra Buttes and Mount Elwell to Spanish Peak, and the second, as shown by Lindgren, lies farther east and extends north toward Honey Lake, forming, at least in part, the east front of the range. These two summit crests in a general way outlined the drainage basin of Jura River, which flowed north between them to the estuarine body of water that probably covered a large part of the Lassen Peak region and connected directly with an arm of the sea in the Sacramento Valley. The estuarine-covered portion of the Taylorsville region was apparently about sea level during the gravel period.

Altitude of the region.—The flora of the Taylorsville region during the gravel period is in strong contrast with that of the same region to-day, and supports the view drawn from the drainage that the northern end of the range during the deposition of the prevolcanic gravels was much lower than now. This statement is not intended to apply to the range south of the fortieth parallel for the streams headed in that direction, and it is evident that the range there had greater altitude. In that direction Lindgren has shown by a careful study of stream grades that since the gravel period the summit of the Sierra has been raised with reference to the Sacramento Valley so as to increase the slope to the southwest.

Jura River Valley.—Jura River headed in the main divide and flowed parallel to its base for many miles before turning more nearly north. West of the river the valley had a short, steep slope from the main crest, while on the east there was a long, gentle slope to a distant crest. The paucity of gravels on the slope east of the river may be taken as an indication of the smallness of the streams as compared with the main river with its well-marked gravel course.

Small masses of gravel containing pebbles of lava were found on Squaw Creek (Pl. II), near Mapes, 4 miles northeast of Chases, and traces occur also in Red Clover Valley, with a larger mass, of lava pebbles only, south of Genesee Valley, but no definite evidence has yet been reported east of the bed of Jura River to indicate the former presence in that region of an important contemporaneous stream.

Drainage of Sierra Valley.—No definite connection has yet been traced between Jura River and Sierra Valley, whose records of the auriferous-gravel period are concealed beneath a cover of volcanic rocks and lake beds. Lindgren has traced the sunken area or moat, as he appropriately calls it, of the Lake Tahoe region as far north as

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Sierra Valley and suggests[a] that during the gravel period the drainage may have been north. So large an area would give rise to a large stream and important deposits would be expected to record its course. A suggestion of its existence may probably be found in the observation of Turner,[b] who reports bowlders and pebbles of rhyolite in the auriferous gravels near Cedar Creek, at the north end of Mohawk Valley lake beds, and remarks "that a portion of this gravel is of later age than that of the Haskell Peak channel, which is capped with rhyolite."

Uplift in gravel period.—The lower portion of the gravel deposits of the main area in the Taylorsville region is sand and the upper portion gravel, often coarse and containing bowlders. This decided and general change in the character of the sediment delivered by Jura River must have resulted from an increase of grade within the pre-volcanic-gravel period, a change which under the circumstances points for its origin to a rise in the main crest of the range about Haskell Peak or farther south.

QUATERNARY.

Gravels of Keddie Ridge.—Three miles directly east of Greenville, on the west slope of Keddie Ridge, at an altitude of 4,100 feet, is a considerable body of well-rounded gravel forming the flattish summit of a spur. The pebbles are chiefly of quartzite, gray, black, and rarely red flinty rocks with fragments of slate and granite, and a few are of andesitic lavas. A prospecting shaft has been sunk 20 feet in gravel and sand and shows the pebbles dipping easterly toward a gap in the Keddie Ridge through which the depositing stream may have passed. The deposit is about 50 feet thick, 200 yards wide, and nearly half a mile long in the direction of the general course of the stream.

Gravels near Greenville.—On the valley border 1 mile northeast of Greenville there is a mass of gravel exposed along the road for over half a mile. It is associated with soft whitish material, which may be volcanic, and is overlain by a sheet of andesitic lava in which pyroxene is the characteristic mineral. The two masses of gravel just noted probably belong to the same stream, which seems to have flowed across the gap of Keddie Ridge from the region of the head of North Arm, and may represent an early diversion of Jura River. Whatever may have been its source the topography of its time was very different from that of to-day.

North Arm pothole.—An interesting pothole occurs on the southeast side of North Arm, near Mr. Thompson's, 1½ miles northeast of Taylorsville. The waterworn rock is the Thompson limestone about 100 feet above the level of the adjacent valley border. The pothole is 2½ feet

[a] Truckee folio (No. 39), Geologic Atlas U. S., U. S. Geol. Survey, 1897, p. 6.
[b] Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, p. 611.

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in diameter and 3 feet deep and contains a lot of well-worn gravel at the bottom to testify in a very satisfactory manner to its origin. There is no stream near it now, and the only reasonable explanation apparent ascribes it to the North Arm stream fashioning the slopes of the valley at that level.

Shoo Fly gravel terraces.—On the right bank of Indian Creek below Shoo Fly there are terraces ranging from 300 to 600 or more feet above the stream. Most of these terraces have a capping of rhyolite or basalt, and some have traces of gravel, but no large body of gravel was observed anywhere except on the low benches near the present stream level. These gravels are evidently of late origin, were deposited by Indian Creek, and according to Lindgren are distinctly connected with the Pleistocene gravels of American Valley.

Glacial moraines.—Glacial phenomena in the Taylorsville region are very meager and confined to the eastern slope of Grizzly Mountains. The small ravine heading against the northern side of Tower Rock had sufficient gathering ground at an altitude of 7,500 feet to give rise to a glacier over a mile in length. Its morainal deposits are strewn over the slope from 6,000 down to nearly 4,500 feet, where there is a prominent terminal mass. Higher up a lateral embankment is well marked on the west side.

A short distance farther north is a small lake due to a small moraine dam. The Devils Punch Bowl is an excellent example of the same sort. Crystal Lake of Houghs Peak is another example, and probably also Taylor Lake, near Kettle Rock.

Valley alluvium.—Valley alluvium is the sediment which fills the valleys and makes the level surface of Indian Valley, North Arm, and Genesee Valley. It contains some gravel, especially where streams enter the valleys. Sand is more widely distributed, but silt is the most common material and makes an excellent rich soil for agriculture.

The depth of the valleys and the character of the material below is not known. No deep borings or wells have been made. It is apparent, however, from the occurrence of the Mounds, which are simply knolls on a spur from Keddie Ridge, that Indian Valley is deepest on the western side.

IGNEOUS ROCKS.

GENERAL ACCOUNT.

The igneous rocks of the Taylorsville region are the same as those of the Sierra Nevada south of the fortieth parallel, which have been described in detail by Turner, Lindgren, and Ransome in various folios and special papers. This renders an extended treatment of them at this place unnecessary.

The igneous rocks include representatives of both acidic and basic types, some intrusive but most of them effusive, and are scattered

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at intervals through geologic time from the early Silurian to the Quaternary. The Paleozoic and early Mesozoic igneous rocks of the Taylorsville region are chiefly lavas which have been much altered from their original condition. To indicate the change the altered forms are designated metarhyolite and meta-andesite.

The earliest eruptive recognized in the Taylorsville region is the metarhyolite at the base of the Silurian quartzite. It is a large mass having a probable thickness of over 1,000 feet. This was succeeded in Carboniferous time by extensive eruptions of meta-andesite of great thickness, separable into three subordinate masses, Taylor meta-andesite, Kettle meta-andesite, and Reeve meta-andesite, each of which is outlined on the geologic map.

During Jurassic time volcanoes were again active near Taylorsville and the Fant and Hull meta-andesites were erupted. A great change took place about the close of the Jurassic, and the intrusive rocks of that time are strongly contrasted with the earlier lavas. Instead of metarhyolites and meta-andesites we have holocrystalline granular rocks, such as granodiorite, serpentine, pyroxenite, and various rocks occurring in dikes. The Tertiary volcanics are of three types, rhyolite, andesite, and basalt.

PRE-SILURIAN.

METARHYOLITE (QUARTZ PORPHYRY).

General description.—This is a massive gray siliceous rock which generally contains phenocrysts of quartz or feldspar embedded in a uniformly fine, compact groundmass. In the most common form on the slope of Grizzly Mountains phenocrysts of feldspar are absent, and those of quartz often inconspicuous or absent, but elsewhere both are usually abundant. Flow lines are not generally present but are sometimes conspicuous. Part of the mass is distinctly fragmental, made up of angular pieces of metarhyolite cemented by material of essentially the same sort. On a weathered surface the fragments usually become much lighter than the true interstitial material and make the brecciated character of the rock conspicuous, and it appears to be a veritable flow breccia. In other portions there are occasional bright-red fragments of various shades and tints which give prominence to its structure. Some of the fragments are rounded, suggesting attrition, while others are amygdaloidal, as if originally vesicular, suggesting volcanic ejection, though no positive fine volcanic tuff was discovered.

Much of the metarhyolite has a decided schistose structure, which is in some places approximately parallel to the lines of flowage. On the lower slope of Grizzly Mountains the structure is very well

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developed and dips to the southwest parallel to the flow lines and the general stratification of the mountains. That this structure is due to compression and consequent shearing is shown by the fact, seen under the microscope, that the grains of quartz are crushed and displaced along the same lines.

Occurrence.—The mass designated as metarhyolite is complex, being made up of surface flows, some of which are thoroughly brecciated, intermingled with much ejected fragmental material spread over the country before the deposition of the Grizzly formation.

Relation to adjacent rocks.—The relation of the metarhyolite to the Grizzly formation is of greatest importance and has already been considered in connection with the quartzite. The pebbles of metarhyolite in the overlying quartzite afford definite and conclusive evidence that the quartzite was deposited upon the metarhyolite. The original surface of the siliceous lava was probably very rough and irregular, and these features have been intensified by deformation. On the lower slope of Grizzly Mountains opposite Huntington the ancient rhyolite has well-marked fluidal structure, in general parallel to the surface on which the quartzite was laid down and subsequently folded.

After determining the relation of the metarhyolite to the Silurian quartzite it is easier to understand its relation to sediments of later age. The Taylorsville formation, like the Grizzly, is folded or faulted into the metarhyolite, but in the case of the Arlington and later formations the sediments overlie the metarhyolite with evidences of less subsequent disturbance.

Distribution.—Metarhyolite is especially wel developed on the eastern slope of Grizzly Mountains. To the southeast it extends as a narrow belt for 11 miles into the Downieville region, where it has been recognized by Turner as made up of volcanic flows. To the north and northwest from Grizzly Mountains its area widens so as to form Keddie Ridge and the hills between Crescent Mills and Greenville and beyond, where it is covered by the later formations. It is possible that the igneous rock of this large area is not all of the same age. A small part of it may belong to the rhyolite erupted at the close of the Jurassic, and occurring as dikes in the earlier form, but the close similarity between the two rocks rendered it impracticable to separate them in all cases.

CARBONIFEROUS.

TAYLOR META-ANDESITE.

General description.—This rock is decidedly green and is generally designated greenstone by the miners. Where not too much altered it is porphyritic with numerous crystals of augite and occasionally

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feldspar, but in most cases the porphyritic structure has been obscured in the development of an imperfect cleavage.

Much of the rock has a decidedly fragmental structure, which is most plainly visible on a weathered surface. The fragments in some places are clearly vesicular and show that the fragmental material is really tuffaceous and represents explosive volcanic action, but it is rarely if ever a coarse agglomerate. In other cases, however, vesicular fragments are few or absent and the rock passes into a fine conglomerate. The matrix, like that of the tuff and the altered groundmass inclosing the phenocrysts of augite, is composed in large measure of secondary hornblende, chlorite, epidote, and quartz. The Taylor meta-augite andesite generally has an imperfectly developed slaty structure and is often traversed by quartz veins, many of which follow the lines of cleavage. Occasionally the rock is full of quartz amygdules, which stand out on the weathered surfaces, giving the rock the aspect of a quartz porphyry.

The phenocrysts of augite are rarely complete crystals. Some of them show one or more crystallographic boundaries, but for the most part they are fragments of crystals irregular in outline. Many of them have traces of a lighter colored fringe of enlargement. Phenocrysts of plagioclase are not common and the groundmass is generally so altered as to be completely replaced by epidote, chlorite, hornblende, and quartz, but where preserved it is made up of minute elongated crystals of feldspar arranged in streams. No definite trace of diabasic structure was found.

Occurrence.—Taylor meta-augite andesite occurs in irregular sheets which represent lava flows from ancient volcanic vents intermingled with clastic material blown from the same craters. One of the best localities to observe the relations is about Taylor Rock, where the tuffaceous portion is well exposed. The mass, as already noted, generally has more or less prominent cleavage planes which strike northwest and southeast, parallel to the general strike of the formation, and dip to the southwest. Owing to deformation and alteration the position of the lava flows and tuffs is difficult to determine, but generally they lie in sheets approximately parallel to the stratification of the sediments between which they outcrop. That this is their true position can be best determined in the canyon of Indian Creek, between Shoo Fly and Arlington Bridge, where the great mass of meta-augite andesite lava and tuff lies conformably between the Shoo Fly and Arlington beds and dips steeply to the southwest.

Distribution.—The same conclusion may be drawn from its general distribution northwest of Houghs Peak, where for over 20 miles it follows along the strike between the Shoo Fly and Arlington formations. Southeast of Houghs Peak, however, its distribution is somewhat less regular. It breaks across the older strata, sending dikes

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into them and covering them in a broader area, which extends south of the fortieth parallel for many miles.

A second and much smaller area lies between the Peale and Robinson formations, crossing Genesee Valley a mile east of the post-office. It seems most probable that the lavas of this small area, though of Carboniferous age, are somewhat younger than those of the Taylor Rock area. The Peale formation apparently belongs between them.

It seems most probable that the masses of meta-andesite west of Taylorsville, as well as that of the mounds in Indian Valley, the point northeast of Crescent Mills, and the larger mass of Keddie Ridge and Keddie Peak, belong to the Taylor meta-augite andesite. Much of it is like the Fant meta-andesite, to be described presently.

Relations to adjacent formations and age.—In considering its occurrence emphasis was placed on the fact that it lies between the Arlington and Shoo Fly formations and would therefore appear to be of contemporaneous eruption interstratified with Carboniferous rocks. Dikes have been found running off from the main mass near Taylor Rock into the Arlington formation, but not into the overlying beds to the southwest.

KETTLE META-ANDESITE.

General description.—The principal rock included under this designation is decidedly porphyritic, with many small phenocrysts of feldspar and some of hornblende, and rarely also a few round grains of quartz. These are embedded in a reddish-brown or gray, partially crystalline groundmass, containing small grains of plagioclase and quartz. This form is most abundant on the prominent spur leading from Peters up to the Lucky S mine, also in Hornfels Point and along the east slope of Wards Creek.

A subordinate but still abundant rock included in the Kettle meta-andesite is pale greenish gray and generally nonporphyritic except in thin section under a microscope where phenocrysts of feldspar are seen altered to epidote and quartz and embedded in a fine groundmass full of feldspar microlites. This form is most abundant along Peters Creek and in the neighborhood of Kettle Rock. Both these forms are intimately associated with fragmental rocks, mainly tuffaceous, but locally passing into fine conglomerate and sandstone.

Occurrence.—The Kettle meta-andesite is clearly of volcanic origin, and its mass is made up of an extended series of lava flows and products of volcanic explosions. The whole mass has been subject to much deformation, so as to obscure the original structure, but the individual sheets of lava and tuff are locally still visible on the steep, rocky canyon slopes of Peters, Surprise, and Lights creeks.

Distribution.—A small area lies south of Genesee Valley, but the main mass extends from Hornfels Point northwest across Peters

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Creek and Lights Creek to Moonlight and Mountain Meadows, where it disappears mainly beneath the mass of Tertiary lavas which cap that portion of the range, and which have not been completely mapped in detail.

Relations to adjacent formations.—The relation of the Kettle meta-andesite to the Robinson, Trail, and Foreman formations, as shown on the map (Pl. III), appears at first glance to be that of an eruptive including dislodged masses of the formations named. It must be remembered, however, that of all the included masses on Hosselkus Creek, Peters Creek, North Arm, Lights and Surprise creeks, only one, that on Peters Creek, contains fossils, and they are in all probability of Carboniferous age. It is evident, therefore, that the relation of the Kettle meta-andesite to the Carboniferous sandstone on Peters Creek is the most important.

The Robinson beds of the limited locality on Peter Creek are red and gray tuffaceous sandstones with marked pencil structure and composed, as in the typical Robinson formation, almost exclusively of particles of volcanic rocks. By the trail they dip southwest at an angle of about 54°, but farther north they appear vertical and so grade into the coarser tuffaceous material by which they are bounded in all directions as to indicate that the sandstone in question is a part of the fragmental material of the great mass of Kettle meta-andesite, and that the volcanic eruptions occurred about the time the Robinson formation was deposited—that is, in the late Carboniferous. It may be noted here that in the Redding region of Shasta County, where the structural relations are much simpler, there are great masses of volcanic material at about the same geologic horizon.

Tuffaceous sandstones were found at a number of localities within the Kettle meta-andesite, but microscopic sections revealed no fossils. Some were not marked on the map, but others were, and it is possible that all may belong to the Robinson formation. This, however, does not seem probable in the areas marked as belonging to the Trail and Foreman formations, where the masses are large and the lithologic resemblance close to the nearest masses of sediments. The long, narrow belt of the Trail formation crossing Hornfels Point is vertical and appears to be folded or faulted down into the meta-andesite. In the Surprise Creek areas the rocks are like those of Evans Peak and have a gentle dip to the southwest directly into the meta-andesite, from which it is most likely separated by a fault.

On the north side of Genesee Valley the Kettle meta-andesite is converted into hornfels along its contact with the granodiorite, showing conclusively that the meta-andesite is older than the diorite. It is important to note in this connection the occurrence in the tuffaceous Kettle meta-andesite conglomerate of pebbles of red jasper

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and of a reddish granitic rock. The latter is composed of red orthoclase and quartz with marked graphic texture and includes a few scales of mica. The jasper may come from earlier Carboniferous rocks, but the source of the other is unknown.

REEVE META-ANDESITE.

General description.—White crystals of plagioclase are plentifully scattered in a compact dark groundmass, giving the rock a conspicuous porphyritic structure. No phenocrysts of augite are present, and the dense groundmass appears largely amorphous and is full of feldspar microlites, generally without any definite ferromagnesian silicate. In one case, however, the groundmass was found to be holocrystalline and composed of many ledge-shaped crystals of plagioclase, with grains of augite and magnetite filling the angular spaces between them as in diabase.

Though some of the material appears to be a solid lava flow, much of it is fragmental yet decidedly porhpyritic, and distinguishable from the other chiefly by the fact that it contains a variety of well-preserved fossils and grades into the sandstone of the Robinson formation. In places the rock has been so squeezed as to develop a slaty structure, in which the phenocrysts of feldspar are drawn out long in the plane of cleavage.

Occurrence and distribution.—It occurs as a definite flow and tuff which forms a long, narrow belt running northwest from Robinson's house in Genesee Valley and bounded on both sides by fossiliferous beds of the Robinson formation. A remarkable expansion of this area occurs a mile northwest of Robinson's and is succeeded in the same direction by a narrow dikelike mass which is remarkable for its schistosity, suggesting that its narrowness is due to compression.

A second belt similar to the first borders the Robinson formation on the west, but its long, slender, dikelike south end does not quite reach Genesee Valley. South of Genesee Valley a small area of the Reeve meta-andesite occurs east of Wards Creek.

North of Indian Valley four areas occur (Pl. II) which have not been mapped in detail. The first and principal area is a long, narrow belt extending northwest from near the Lucky S mine to Moonlight; the second is at the head of Cooks Canyon, and the other two lie on the slopes east of Mountain Meadows in line with the principal mass already noted.

Relation to adjacent formations and age.—The intimate association of the lava and tuff with the Robinson formation, into which the tuff grades, as well as the fossils contained in the tuff, fixes the age of the igneous eruption as in the late Carboniferous. The long southern extremity of the western area has the form of a dike cutting the earlier meta-augite andesite, which may belong to the same horizon as that of

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Taylor Rock, though it seems to be somewhat later in the Carboniferous. These horizons of vigorous volcanic activity in the Carboniferous correspond closely to those of the Redding region of Shasta County described in the Redding folio.

The relation of the Reeve meta-andesite to the Kettle meta-andesite is not clear, though it appears to penetrate the volcanics as a dike, indicating that the Kettle meta-andesite is the older.

JURASSIC.

FANT META-ANDESITE.

General description.—The Fant meta-augite andesite is a greenish to reddish-brown rock which is more or less porphyritic, sometimes with augite, but often with plagioclase in a groundmass made up of small crystals and grains of feldspar, augite, and magnetite, and generally with some amorphous matter. Occasionally it is conspicuously porphyritic with an abundance of greenish crystals of plagioclase in a reddish groundmass. When the phenocrysts are of augite they are inconspicuous in a greenish groundmass. The most abundant form of this meta-augite andesite is fragmental, and it is composed of material ejected by volcanic eruption, so that it is tuffaceous. It is generally fine, the fragments being under an inch in diameter and often amygdaloidal.

Occurrence and distribution.—The Fant meta-augite andesite occurs in flows, forming with its associated tuff irregular layers parallel generally to the stratification of the adjoining sedimentary rocks. The flows and tuffs being irregular, it is difficult to determine their general position, but where best exposed they dip to the southwest.

It forms a broad belt extending a little west of north from the lower slope of Grizzly Mountains across the western slope of Mount Jura to North Arm of Indian Valley. The south half of the belt is narrow, but the north half is wide and irregular.

Relation to adjacent formations and age.—Along the west slope of Mount Jura at a number of points the Fant meta-augite andesite contains included fragments of the adjacent Hardgrave sandstone, so there is no reasonable doubt that the meta-augite andesite is younger than the Hardgrave sandstone, though in the overturning of the Jurassic strata on Mount Jura the Hardgrave sandstone was placed on top of the meta-andesite.

On the other hand, this overturning of the Jurassic rocks has brought the meta-andesite on top of the Thompson limestone. At both the north and the south end of Mount Jura, as well as on its western slope directly south and southwest of the summit, the Fant meta-andesite lies between the Hardgrave sandstone and the Thompson limestone, and while it contains fragments of the former the

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contact with the latter is such as to show the deposition of the limestone on the meta-andesite. This portion of the meta-andesite is of volcanic effusion during the early Jurassic in the interval between the deposition of the Hardgrave sandstone and the Thompson limestone.

HULL META-ANDESITE.

General description.—This greenish to reddish meta-andesite is like the Fant meta-andesite just described, though the fragmental phase and the porphyritic phase rich in feldspar phenocrysts are relatively not so abundant. The prevailing type is greenish and essentially nonporphyritic, and occasionally in the Little Grizzly Creek region it is decidedly amygdaloidal.

The rock in general is only partially crystalline and is made up essentially of plagioclase and augite or their alteration products, chiefly epidote, chlorite, and some quartz. In a few cases it was found wholly crystalline, with the angular spaces between the crystals of plagioclase filled with augite and magnetite as in diabase. In a few cases also, especially in the dikes cutting the metarhyolite, it contains primary granular quartz in the groundmass as in the quartz-augite diorites.

Occurrence and distribution.—Much of it is in more or less well-defined sheets representing lava flows and tuff and is exposed in the neighborhood of Little Grizzly Creek, where the older rocks are generally covered. The mass which splits the belt of Peale beds southeast of Genesee is intruded between the strata. North of Indian Creek the mass narrows and becomes dikelike. It is decidedly slaty and near the divide cuts across the belt of Peale beds as well as the later formations to the east. More definite dikelike masses occur on the north and south slopes of Mount Jura, and it is possible that it occurs also as dikes within the area marked as Fant meta-augite andesite but was not recognized. Definite dikes occur also cutting the metarhyolite and sedimentary rocks just north of Tower Rock and elsewhere along the slopes of Grizzly Mountains.

Relation to adjacent formations and age.—The fact that it penetrates the Mormon sandstone, and especially also the Foreman beds northeast of Mount Jura, indicates that its eruption took place after the deposition of the Foreman formation and most likely near the close of the Jurassic.

LATE JURASSIC OR EARLY CRETACEOUS.

SERPENTINE.

General description.—Much of the material included under this designation is typical green serpentine which readily splits up into slickensided lenticular pieces, but it contains nodules and large masses of a prevailingly dark rock with the texture of granite but

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exceedingly tough. This rock is enveloped and permeated with serpentine and shows the rock from which the serpentine was derived by alteration. It varies greatly in composition. The most abundant form is composed almost wholly of a light-colored pyroxene with a small amount of dark-green hornblende. Occasionally the hornblende increases and plagioclase appears, so that the rock passes into phases related to gabbro or diorite, though it is for the most part a pyroxenite. Serpentine is frequently derived from peridotite—that is, a rock rich in olivine—but in the serpentines of the Taylorsville region no definite trace of olivine was found.

Distribution, relation to other rocks, and age.—The serpentine of the Taylorsville region occurs in irregular stocks like that of Grizzly Mountains and Round Valley Reservoir, but may be elongated like that of Montgomery Creek or run out into long, narrow dikes like those of the east slope of Grizzly Mountains. The serpentine intersects the metarhyolite of Grizzly Mountains and all the Paleozoic rocks with which it is associated in the Taylorsville region, but does not come in contact with later sediments. On the other hand, the serpentine is cut by quartz diorite and dikes of the later rhyolite, and belongs among the first eruptions of the late Jurassic or early Cretaceous.

GRANODIORITE.

General description.—The rock included under this head is a light-colored and for the most part medium-grained rock which looks like granite. It is composed chiefly of plagioclase feldspar and quartz, with a small amount of dark-green hornblende and black mica and a trace of orthoclase, magnetite, pyroxene, and other accessory minerals. One of the best exposures of this rock is by the road near Flournoy's, at the head of Genesee Valley. At different localities the relative proportions of the minerals named above vary greatly. The rock is generally quartz diorite, but locally the orthoclase may increase and the rock passes into granodiorite. Pyroxene occasionally becomes prominent near the borders of the mass and the rock passes into quartz-pyroxene diorite, a good example of which occurs on the Cosmopolitan mine road, 2 miles west of Flournoy's. The abundance of pyroxene and the almost complete absence of quartz gives this finer grained rock a darker color than that of Flournoy's. Another variation which is peculiar in containing tourmaline occurs south of Moonlight. It is dark colored and fine grained, with considerable quartz and much hornblende, sometimes grouped so as to make the rock dark spotted. The dark-brown tourmaline is not prominent in the hand specimen but becomes so in thin section, where the crystals are seen to be grouped with radial arrangement.

Occurrence and distribution.—The quartz diorite and granodiorite which form the bulk of the north end of the Sierra Nevada east and

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northeast of Genesee Valley are part of the great mass of the range farther south. Their apparently irregular distribution is due to the partial cover of Tertiary volcanics. Near the head of Mountain Meadows is a mass of quartz diorite, which is separated into several areas by auriferous gravel. It is rich in quartz and hornblende, and fine grained like that along the western border of the great mass about Lights Canyon. Several isolated dikelike masses occur, one along Houghs Creek southwest of Taylorsville, between the Taylorsville and Arlington formations, and another northeast of Crescent Mills, where it cuts metarhyolite. A small round mass cuts the serpentine southwest of Greenville, and a similar but smaller mass occurs near the fortieth parallel in the Kettle meta-andesite.

Relation to adjacent formations and age.—On the north side of Genesee Valley the quartz diorite comes in contact with the Swearinger slate, the Trail formation, and the Kettle meta-andesite. Along the contact the quartz diorite has locally converted adjacent portions of all these formations into dark flinty hornfels, which is abundant in places along the crest of Hornfels Point. While it is certain that the irruption of the quartz diorite took place after the deposition of the Trail formation, its relation to the other Jurassic formations in the Taylorsville region could not be determined. In the Downieville region, however, Turner has shown that the irruption occurred after the deposition of the Milton formation, which is equivalent to at least part of the Taylorsville Jurassic.

As to its neighboring igneous rock, the quartz diorite is clearly younger than the Kettle meta-andesite and the metarhyolite which it intersects, but in the canyon north of Round Valley Reservoir it is cut by dioritic dikes, which must be considered the younger.

VARIOUS DIKE ROCKS.

General description.—The most common dike rock varies in color from light gray to pale green and reddish brown. Small phenocrysts of quartz are always present, but it is rarely porphyritic, except in the reddish-brown form, which is full of phenocrysts of feldspar. It is rhyolite, but lacks entirely the brecciated feature which is so generally prominent in the metarhyolite, and in but few localities does it show fluidal structure.

Another form, which has no quartz phenocrysts and looks much less siliceous, is made up almost wholly of plagioclase and green hornblende. It is a fine-grained greenish diorite. The occurrence and distribution of the rhyolite will be considered first and then that of the diorite.

Occurrence and distribution.—The forms are distinct dikes and small circular or angular patches. One and a half miles west of Greenville there are a number of dikes running a little west of north

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through a small area of banded slates belonging to the Taylorsville formation. The largest of the dikes is about 75 feet in width, but could not be traced more than a mile along the strike.

From Round Valley Reservoir, about one-third of the way down North Canyon to Greenville, the granitic rock is intersected by a dikelike mass of rhyolite nearly 100 feet in width. It forms prominent cliffs and falls along the stream. Just below the Phœnix Mill the dike strikes nearly east and west. Locally the rock looks like a microgranite, and under the microscope shows remarkable graphic intergrowths of quartz and feldspar.

A mile and a half west of Taylorsville there are four dikes and irregular patches of rhyolite apparently cutting the meta-augite andesite and Taylorsville formation, while 2 miles south of Taylorsville distinct dikes of rhyolite occur in serpentine.

On the west slope of Mount Jura there are a number of small masses of rhyolite. Those associated with small areas of Hardgrave sandstone have been derived by faulting from the large mass to the west, but some of the others appear to be intrusive in the meta-andesite. The most distinctive mass, nearly circular in outline, occurs about a mile southwest of the summit of Mount Jura. The rock is reddish brown in color and decidedly porphyritic, with many small crystals of feldspar and quartz. The quartz is rounded and embayed, and the feldspar is at least in part plagioclase and generally much altered. Microscopic traces of altered hornblende are scattered through the groundmass. The relations of this mass to the adjacent meta-andesite were not clearly made out, but it is believed that the rhyolite penetrates the meta-andesite.

A short distance farther south is a dikelike mass of rhyolite nearly a mile in length. The rock is greenish and nonporphyritic, like the dikes in the serpentine, and appears to hold the same relation to the meta-andesite as the porphyritic type just noted.

Half a mile northwest of the summit of Mount Jura is a mass of rhyolite cutting across a belt of meta-andesite that intersects the Mormon sandstone, and near the center of section 24, 2½ miles northeast of Taylorsville, is a small mass lying between the Mormon sandstone and meta-andesite. A third mass, about a mile north 10° east from the summit of Mount Jura, penetrates the Foreman beds. All three masses are long and narrow and appear to be dikes, but on the divide east of Mount Jura, at the head of Hinchman Ravine, is another circular mass similar to that on the west slope of Mount Jura. It penetrates the Peale formation of Carboniferous age as well as the associated meta-andesite, and is remarkable locally on account of its distinct fluidal structure. A similar mass, holding essentially the same relations to adjacent rocks, occurs on Little Grizzly Creek near the fortieth parallel.

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The dikes of diorite were noted in the canyon north of Round Valley Reservoir. They are vertical, range from 5 to 10 feet in width, strike nearly north and south, and cut directly through the lighter-colored, coarser-grained granitic rock. Their relation to the dike of rhyolite in that vicinity was not satisfactorily determined.

Relation to adjacent formations.—In considering their occurrence and distribution the relations of the rhyolite and diorite dikes to adjoining rocks in each locality were brought out, and they appear to intersect sediments belonging to Silurian, Devonian, Carboniferous, and Jurassic formations, as well as meta-andesite, serpentine, and granodiorite among igneous rocks. They are evidently of late Jurassic or early Cretaceous intrusion. This relation to sedimentary and igneous rocks distinguishes the rhyolite dikes from the meta-rhyolite, which is of early Paleozoic volcanic effusion.

MIOCENE.

RHYOLITE.

General description.—Rhyolite is a siliceous lava, generally light colored or brownish and more or less porphyritic, with grains of quartz and sometimes with scattered crystals of feldspar or biotite. All of these forms occur in the Taylorsville region in the small areas on the ridge west of Shoo Fly and half a mile south of Greenville. Perhaps the most definite rhyolite masses of the Taylorsville region are tuffs which occur in the auriferous gravels near the head of Willards Creek, 10 miles southwest of Susanville. They are grayish white and composed almost wholly of splinters and pumiceous fragments of volcanic glass. The following chemical analysis of it was made years ago by George Steiger and published in United States Geological Survey Bulletin No. 228, page 211:

Analysis of rhyolitic tuff from Willards Creek, near Susanville, Cal.

SiO_2	70.01	K_2O	5.12
Al_2O_3	12.61	H_2O at 100°	2.37
Fe_2O_3	1.47	H_2O above 100°	4.68
FeO	.50	P_2O_5	.04
MgO	.72	MnO	Trace.
CaO	1.06		100.52
Na_2O	1.94		

Distribution and relations.—On the ridge west of Shoo Fly are two small areas of rhyolite. They differ somewhat in color, yet possibly belong to the same flow. At the southern locality the rhyolite apparently overlies gravel and is itself overlain by a flow of basalt.

South of Greenville is a small mass elongated nearly north and south and not far from the course of the line which connects the other two detached masses. It is possible, but not probable, that all these small masses are remnants of the same flow.

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Some rocks which may be rhyolitic were noted during a reconnaissance along the road in Last Chance Valley and on the eastern crest between the road and McKesick Peak. The rock is generally tuffaceous, coarser than that already noted, and not clearly rhyolitic. It lies directly on the granodiorite and is overlain by basaltic flows.

South of the fortieth parallel, in the region mapped by Lindgren and Turner, rhyolite and rhyolitic tuff are more abundant, and they directly overlie the earlier auriferous gravel. The same horizon is probably represented by the rhyolitic tuff on Willards Creek, which, on account of the smallness of the area, is included on the map (Pl. II) in the auriferous gravels.

PLIOCENE.

ANDESITE.

General description.—Andesite is a lava, usually light gray, which, though not generally porphyritic in the hand specimen, becomes more or less clearly so in thin section. Crystals of plagioclase are numerous; those of hornblende, biotite, and pyroxene are somewhat less abundant but in various proportions. The felty dark gray groundmass inclosing the phenocrysts contains many minute microlites of feldspar and black grains of magnetite in a light-brown glassy base.

In some cases the hornblende phenocrysts are abundant, surrounded by dark borders, and the rock is a typical hornblende andesite. In other cases hornblende is practically absent and pyroxene is the characterizing mineral. All these forms are generally accompanied by a great deal of andesitic breccia and tuff from explosive volcanic action.

Occurrence and distribution.—It occurs in sheets, forming a blanket covering the older rocks around the volcanic vent from which the flows and ejected material issued. There were many vents, and the cover was continuous over a large part of the region. Erosion has removed the cover in places and left isolated patches, sometimes revealing the volcanic necks through which the material reached the surface. This is especially the case in Lone Rock, which is a conspicuous peak surrounded by cliffs. A less conspicuous example occurs in Indian Creek, between Lone Rock and Thompson Peak. Both of these masses are of hornblende andesite, closely related to that north of Kettle Rock, as well as the isolated patches near Hosselkus Valley, on Hornfels Point, and on the divide at the head of Foremans Ravine.

The andesite by the chalybeate soda spring near Arlington Bridge is black and breaks with very irregular fracture. It is slightly porphyritic with crystals of plagioclase embedded in a groundmass full of small lath-shaped feldspars with grains of augite embedded in a dark globulitic base. The lava came down from the slope a short

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distance south. The andesite overlying the gravel a mile northeast of Greenville is much richer in augite and poorer in amorphous matter than that of the Arlington spring. Its source is not definitely known, but it probably issued from a vent at the southeast end of the exposure.

The large continuous sheet of volcanic rocks along the fortieth parallel, about the heads of Squaw and Last Chance creeks, is in part hornblende andesite, with some pyroxene andesite and a smaller proportion of basalt and rhyolite which has not been mapped separately.

The andesitic tuff and breccia which form Diamond Mountain are full of black-bordered hornblende, but in Red Mountain the hornblende has largely disappeared and the prevailing ferromagnesian silicate is pyroxene.

The area between Moonlight and Mountain meadows is mainly hornblende andesite on the eastern side and pyroxene andesite on the western slope, though the two are intermingled. The same is true of the Cheney Creek area and the small area north of Nanney, but the larger mass which forms the end of this part of the Sierra Nevada is almost wholly pyroxene andesite.

North and east of Susan Creek much of the country has not been seen. A general reconnaissance was made by J. Stanley-Brown in 1890. Hot Springs Peak, an old volcano, was visited and is known to be andesite, though the rocks about its north base are basalt. Shaffer Peak is supposed to be of the same character.

Relation to adjacent formations and age.—North of Kettle Rock, about the head of one of the tributaries to Lights Creek, the andesitic breccia overlies auriferous gravel, and the same is true north of Moonlight, where the auriferous gravel, firmly cemented, dips westerly beneath the andesites which form the crest. The andesites and andesitic breccias in the Taylorsville region, like those of other portions of the Sierra Nevada, overlie the earlier auriferous gravels.

The earlier auriferous gravels contain many pebbles of igneous rocks derived in large measure from the Paleozoic and Mesozoic lavas already described, which are so widely distributed about the north end of the Sierra Nevada. The early gravels contain also some fragments of lava which appear less altered than those just referred to, but exposures of such lavas were not definitely recognized and distinguished from the Tertiary lavas which overlie the older gravels.

On the other hand, as explained under "Auriferous gravels," the later gravels overlie andesitic flows and are composed in some cases almost wholly of andesitic pebbles. It seems evident, therefore, that the eruptions of andesite occurred within the gravel period, overflowing the earlier gravels and furnishing the material for the later gravels.

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QUATERNARY.

BASALT.

General description.—Basalt is lava which is generally darker colored, more compact, and heavier than andesite, and, though not plainly porphyritic, yet, unlike the andesite, it frequently contains visible grains of yellowish-green olivine. In thin section it is seen to be composed chiefly of plagioclase and augite and a smaller proportion of olivine and magnetite. The dark-gray forms are holocrystalline, but the darker, compact ones have, besides the more or less abundant crystals of plagioclase, much black amorphous matter instead of augite.

Occurrence and distribution.—Basalt is somewhat less abundant than andesite in the Taylorsville region. Like andesite, it occurs generally in flows about a volcanic vent. Mount Ingalls, just south of the fortieth parallel, is a large volcano built up almost wholly of basalt. Turner has shown in the Downieville folio that Mount Ingalls is made up of earlier and later basalts, separated at least in part by a mass of andesitic tuff. The later basalt forms the bulk of the mountain and extends north over the quartz diorite to near Genesee Valley. It is dark gray, holocrystalline, and rich in augite. The earlier basalt appears along the road south of Flournoy's. It is black and compact and contains much amorphous matter. At this point the two basalts are not separated by andesite, and they are not distinguished on the map of the Taylorsville region for the reason that the subdivision of earlier and later can not be applied throughout the region. For example, the youngest basalt of the region is a flow which followed Susan Creek for miles. It is later even than the later basalt of Mount Ingalls and yet most like the older basalt.

One of the finest exposures of basalt in the region occurs at Thompson Peak, opposite Janesville. The eastern slope of Thompson Peak is a steep bluff exposing a succession of basalts and tuffs in layers from 5 to 30 feet thick dipping gently to the southwest. The exposed thickness is apparently about 1,200 feet, and the lower flow in contact with the quartz diorite is very dark and compact, like the earlier basalt of Mount Ingalls. Some of the succeeding layers are vesicular, rich in olivine and much black globulitic base instead of augite. The summit of Thompson Peak is of holocrystalline basalt, with considerable olivine, but rich in augite occupying the angular spaces between the lath-shaped crystals of plagioclase.

Beneath Thompson Peak, on the slope toward Janesville, there are numerous dikes of basalt cutting the diorite. Some run nearly parallel with the crest of the range, and others in various directions, as if Thompson Peak were a volcanic center from which they radiated.

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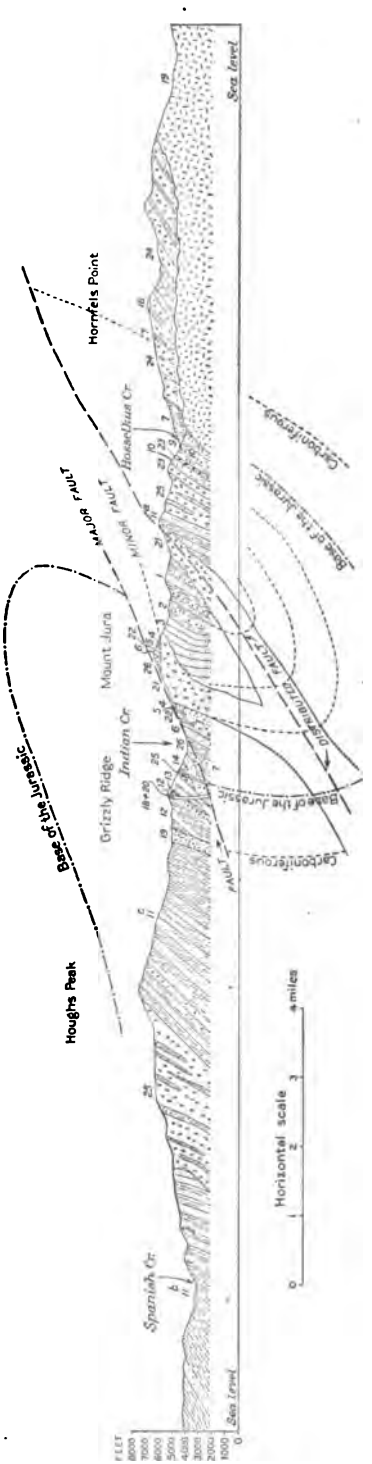

FIG. 11.—General section of the Taylorsville region. *Sedimentary.*—Jurassic: 1, Foreman formation; 2, Hinchman sandstone; 3, Bicknell sandstone; 4, Mormon sandstone; 5, Thompson limestone; 6, Hardgrave sandstone; 7, Trail formation. Triassic: (8, Swearinger slate, does not appear on line of section); 9, Hosselkus limestone. Carboniferous: 10, Robinson formation; 11, Calaveras group, (*a*) Peale formation, (*b*) Shoo Fly formation, (*c*) Arlington formation. Devonian: 12, Taylorsville formation. Silurian: 13, Montgomery limestone; 14, Grizzly formation. *Igneous.*—Quaternary: 15, Basalt. Neocene: 16, Andesite; 17, rhyolite. Late Jurassic (early Cretaceous): 18, Various dikes; 19, granodiorite; 20, serpentine. Jurassic: 21, Hull meta-andesite; 22, Fant meta-andesite. Carboniferous: 23, Reeve meta-andesite; 24, Kettle meta-andesite; 25, Taylor meta-andesite. Silurian: 26, Metarhyolite.

A number of small areas of basalt occur on the steep slope of the Sierra Nevada north of Thompson Peak, but the most interesting area is a small one on the very crest, a short distance south of Diamond Mountain. This little mass, not a hundred yards long east and west, lies nearly flat across the crest and ends in a bluff on the east. It is somewhat amygdaloidal, with definite flow structure from the east, and in this respect agrees with the flow structure seen in some of the flows exposed on the northeast slope of Thompson Peak.

The largest area of basalt is that which surrounds and covers the end of the range north of Mountain Meadows and in succeeding flows descends the valley of Susan Creek. It is part of the great flow which comes from the region of Lassen Peak. There may be other large areas of basalt east and southeast of Susanville, but the hasty reconnaissance of that region by J. Stanley-Brown did not permit their detailed separation from the andesites.

As already stated, the latest basalt flow of the Taylorsville region is that which follows the course of Susan Creek. Others

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have followed watercourses, but their preservation is far less complete. Remnants of successive flows widely separated in time occur in the Shoo Fly region. On the crest of the spur west of Shoo Fly are two remnants of an old basalt flow in part covering rhyolite. At several lower levels are lava-capped benches which are remnants of successive flows that have occupied the bed of Indian Creek and been almost wholly removed by erosion.

STRUCTURE.

GENERAL STATEMENT.

The general structure of the Taylorsville region, as far as its sedimentary rocks are concerned, is shown in the accompanying (measured) section (fig. 11), which represents a tract 17 miles in length. Beginning on the southwest, at an elevation of 3,100 feet on Spanish Creek, it crosses Houghs Peak at 7,254 feet, and reaches Indian Creek, 1½ miles above Taylorsville, at an altitude of 3,500 feet. Continuing in the same course, it crosses Mount Jura at 6,000 feet about one-third of a mile south of the summit. The upper portion of Hinchman Ravine and other small ravines are crossed to reach Hosselkus Creek, 2¾ miles above Genesee, at an elevation of 4,050 feet. Thence the section passes over the northern portion of Hornfels Point at an elevation of 6,500 feet and skirts along the top of the southern slope of the mountain, whose summit is 3 miles directly north of Flournoy's.

The strike of the rocks throughout the region is N. 5° to 65° W., and the dip, with rare exceptions in the Shoo Fly and Foreman formations, is toward the southwest at angles varying from 39° to 75°.

The region traversed by the section may be divided into three belts: (1) The Mount Jura or middle belt, characterized by overturned strata; (2) the Grizzly Mountains or west belt, in which the strata are not overturned; and (3) the east belt, of diorite, which forms the eastern part of the range.

MOUNT JURA BELT.

The Jurassic strata of Mount Jura have been completely overturned. Their general dip is to the southwest. The Hardgrave sandstone lies on top, with the Thompson limestone, Mormon sandstone, Bicknell sandstone, Hinchman tuff, and Foreman beds in a descending but successively younger series dipping beneath the Hardgrave sandstone. This order of superposition is well exposed on the west slope of Mount Jura, and also on the slope toward Hinchman Ravine. The formations are all well characterized by fossils. As there can be no question concerning their relative age determined by Professor Hyatt, it is evident that they have been overturned.

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The overturning involves also the Triassic and Carboniferous strata east of Mount Jura on Hosselkus Creek, where the Trail beds of the Jurassic dip beneath the Swearinger slate and Hosselkus limestone of Triassic age, and these in turn dip beneath the Robinson formation of Carboniferous age.

The belt of overturned strata, embracing those of Mount Jura, after which the belt is named, and the country to the east as far as Hornfels Point, is 6 miles in width. The strata involved have a thickness of about 9,000 feet. All of the strata in this belt are overturned toward the northeast, and this is evidently the result of a great thrust from the southwest.

GRIZZLY MOUNTAINS BELT.

The Grizzly Mountains belt of strata, lying southwest of Indian Creek, is over 12 miles in width in the Taylorsville region and extends beyond its limits. The oldest strata, those of the Grizzly formation, are Silurian, and they dip to the southwest. They are overlain in regular succession by the Montgomery limestone, Taylorsville formation, and Arlington beds, all Paleozoic, and also by a great mass of interbedded volcanics, succeeded by the Shoo Fly formation of Carboniferous age. The whole mass has a thickness of over 14,000 feet. The dip between Indian Creek and Houghs Peak is not over 45°, but west of the volcanics, in the Shoo Fly formation, the dip is increased and may be reversed to a limited extent by local causes. On the whole, this belt is strongly contrasted with that of Mount Jura in that the sedimentary rocks of the Grizzly Mountains belt are older than the middle Carboniferous, are only moderately disturbed, and occur in regular succession, while those of the Mount Jura belt are all younger and much disturbed with interrupted succession.

GRIZZLY MOUNTAINS ANTICLINE.

The Grizzly Mountains belt of strata dipping to the southwest appears to be one arm of an anticline of which the other arm has disappeared. The anticline was overturned toward the northeast by thrust from the southwest. Continued thrusts broke the arch and gave rise to an overthrust fault on which the southwest arm of the anticline appears to have been shoved up over the northeast arm, as shown in the section in fig. 11. This movement and consequent erosion brought to the surface the metarhyolite upon which the Hardgrave sandstone was deposited in the early Jurassic.

MOUNT JURA SYNCLINE.

Adjoining the Grizzly anticline upon the northeast is the Mount Jura syncline, a region of subsidence which may have continued an area of deposition long after deposition ceased over the crest of the

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Grizzly arch, and thus became filled with strata which have no equivalents in the Grizzly arch or on the southwest slope of the Sierra Nevada.

The earliest evidence of this sort concerning the Mount Jura syncline is the presence of the Robinson formation, which is the latest Carboniferous known in the Sierra Nevada, and which lies northeast of the main crest of the Sierra Nevada chiefly in the Mount Jura syncline, and indicates that the Mount Jura syncline may have begun as early as the Carboniferous. Later the same region of depression received an extensive series of Triassic and Jurassic deposits not found west of the main crest at the north end of the range.

The thrust from the southwest which overturned and faulted the Grizzly arch overturned the adjoining arm of the Mount Jura syncline. In Mount Jura and the country to the east, including Hornfels Point, there is no repetition of strata, a feature which indicates that all belong to the southwest arm of the syncline, for all are included in the overturning. The relation of the adjoining portions of the Grizzly anticline and the Mount Jura syncline, though well exposed in the line of the general section (fig. 11), may be seen to advantage 2 miles farther southeast, where several patches of Hardgrave sandstone occur on the lower slope of Grizzly Mountains.

The structure of the syncline is not as simple as it was formerly supposed. The irregularity in the distribution of the Carboniferous, Triassic, and Jurassic within the syncline may be attributed to the folding of the Carboniferous, and later of the Triassic, before the Jurassic strata were deposited.

The entire disappearance of the Jurassic portion of the eastern arm of the syncline is most probably due, as shown in the section, to a large amount of distributed thrust faulting—the Hull fault, that gave rise to the prominent slaty structure in the mass of Hull meta-andesite which separates the youngest Jurassic (1) from the Carboniferous (11, *a*). This igneous rock appears to have been intruded diagonally into the syncline and afforded a plane of easy displacement to relieve the strain in that greatly compressed mass.

TAYLORSVILLE FAULT.

The fault developed between the Grizzly Mountains arch and the Mount Jura syncline lies near Taylorsville and follows approximately the eastern border of the metarhyolite from the lower slope of Grizzly Mountains through the canyon of Indian Creek above Taylorsville and along the eastern slope of Keddie Ridge, as indicated on Pl. III. The metarhyolite a mile northeast of Taylorsville is greatly crushed and evidently marks the course of the fault.

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This fault appears to have been a line of displacement during the latter portion of the Carboniferous and to have aided in large measure in bringing the metarhyolite to the surface, so that in the Jurassic the Hardgrave sandstone was deposited on the same rock which received the Grizzly quartzite in the Silurian.

It was motion along essentially the same narrow zone that folded and overturned the strata in the Mount Jura syncline. Of this there is proof in the southern slope of Mount Jura, where the Hardgrave sandstone, Thompson limestone, and Mormon sandstone, with the associated metarhyolite and Fant meta-augite andesite, are repeated by a fault in the same order and position. This displacement followed the overturning, for the fault enters the overturned beds and shoves them along farther in the same direction.

The hade of the Taylorsville fault appears to be about the same as the west slope of Mount Jura, where some faulted masses cling to the slope dipping southwest into the base of Grizzly Mountains, but toward the summit of Mount Jura the fault plane enters the mountain and passes through to the other side, emerging at the base of the Mormon sandstone. The faulted mass is over 2 miles in length and half a mile in width, and much lower at the southern than at the northern end.

The amount of displacement on the Taylorsville fault near the close of the Paleozoic may have been great, but no data are available for its estimation. As to the post-Jurassic faulting along this line, the amount can be measured in miles, for a large part of the movement was involved in the overturning, and after the overturning was complete the movement on the fault was about a mile.

The Taylorsville fault does not extend far southward. No movement in its line was detected by Turner south of the fortieth parallel, and it is of importanee to note that in the Downieville quadrangle all the Jurassic strata lie east of the axial line of the Grizzly anticlinal, and what is of greater significance is that they all dip to the east; that is, they have not been overturned like those of the Taylorsville region.

Near the fortieth parallel an ancient stream bed of auriferous gravel crossed the line of the fault, but has suffered little if any dislocation at that point, though elsewhere in the same region there has been extensive faulting since the gravel period.

HULL FAULT.

The Hull fault is a branch of the Taylorsville fault and circumscribes the mass of Mount Jura on the east. It follows the Hull meta-andesite throughout the greater part of its course from the fortieth parallel northwest to North Arm. The fault adjusts the overturned Jurassic strata on the west to the Carboniferous on the east and is expressed in the decided slaty structure of the Hull meta-andesite.

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HONEY LAKE FAULT.

In the neighborhood of Honey Lake the Sierra Nevada is bounded on the northeast by a prominent escarpment due to faulting. The escarpment, about 2,000 feet in height, is composed of quartz diorite, which is overlain on the crest by auriferous gravel with a local capping of andesitic breccia in Diamond Mountain, as illustrated in fig. 10. Lava and gravel similar to those of the summit are found locally along the foot of the escarpment, but in most places they are covered by later deposits. Following the escarpment northwest to Gold Run, where the wagon road crosses the range, the gravel is found to be firmly cemented and bent down over the eastern slope of the range so as to connect that of the mountain crest and foot. The escarpment ends at this point and the fault by which it was produced passes into a monoclinal fold. The fold continues to the northwest in the old lavas of the region for about 12 miles and then disappears beneath the newer lavas from the vicinity of Lassen Peak.

From the fact that the Honey Lake fault passes into a monoclinal fold, it is evidently a normal fault and strikingly unlike the Taylorsville fault. The total displacement of the Honey Lake fault is at least 2,000 feet and may be somewhat greater, and it is clearly later than the auriferous gravels and andesitic flows of the Diamond Mountain region.

To the southeast, as shown in Pl. I, the Honey Lake fault extends through a portion of Long Valley into Nevada, where it apparently turns more to the south and possibly connects more or less directly with the main fault along the east front of the Sierra Nevada, which Lindgren has traced as far north as Reno.

In the Truckee region Lindgren has recognized three faults, approximately parallel. The main fault, the one just referred to, lies close along the eastern front of the range from Markleeville to Reno. The other two (see Pl. I) are farther west, one on either side of Lake Tahoe, and bound the sunken area or moat, as Lindgren[a] appropriately designates it, which extends as far northwest as Sierra Valley. East of Lake Tahoe is a prominent ridge or "buttress" which extends up between the Tahoe moat and the sunken region of the Great Basin.

According to Lindgren, these faults were formed during the early Cretaceous. On the eastern fault there was a displacement of 3,000 feet in the early Cretaceous, followed at the close of the Miocene by a displacement of 2,000 feet. This final movement in all probability was contemporaneous with the faulting along Honey Lake.

It is probable that movements along that fault have taken place in recent times, if earthquakes may be accepted as evidence in that direction. A few years before 1885 there were a number of small

[a] Jour. Geology, vol. 4, 1896, p. 895.

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earthquakes whose region of greatest intensity lay along the foot of the Honey Lake escarpment, particularly at Janesville, where objects were thrown from the walls and mantles in dwellings and chimney tops were overthrown. Although the earthquakes were probably due to slight movement along the old fault plane, yet no fissures were visible on the surface, as was the case along Inyo Valley after the great earthquake of 1872.

MOHAWK VALLEY FAULT.

The fault along the west side of Lake Tahoe (Pl. I) Lindgren has traced northwest from Mount Tallac by way of Donner Lake, Lake Independence, and Webber Lake up toward the southwest corner of Sierra Valley and Mohawk Valley, where it has been studied in detail by Turner, who remarks in the Downieville folio that—

> The best evidence that a great displacement has occurred here in Tertiary time consists of the presence of river gravels on the high plateau to the west. At one point about 2½ miles northwest of Haskell Peak there is a heavy mass of well-rounded gravel at the very edge of the escarpment, and a considerable portion of this mass has by gravity traveled down the slope, so that the apparent thickness of the deposit is about 500 feet. To the northeast and west of Haskell Peak, and also close to the edge of the escarpment, are smaller masses of similar gravel, all of them capped with rhyolite and all at an elevation of about 7,000 feet. It is evident that we have here remnants of an old river deposit formed by a stream flowing at a moderate grade. It is not likely that such a stream could have existed along the edge of a plateau having a steep escarpment. There can be no reasonable doubt that since these gravels were deposited a profound displacement has occurred, in virtue of which that portion of the former plateau lying to the east of the present escarpment has dropped down 2,000 or more feet and now lies buried beneath the sediment of the former Mohawk Lake and beneath the Tertiary lavas.

An earthquake occurred in this valley in 1876, which resulted in forming a fissure 2 feet wide and invigorating a number of hot springs along the line of the former fault.

Northwest of Mohawk Valley Turner has found fault scarps at a number of points, but especially along Spring Garden Creek and farther west along the base of Spanish Peak in Meadow Valley, where there appears to have been a displacement of 3,000 feet since the deposition of the auriferous gravels. This fault has been referred[a] to as the American Valley fault. Continuing northwest in the line of the faulting across North Fork of Feather River, about the head of Chip Creek, several faults occur in the lavas of the Lassen Peak region. Forty miles farther northwest, in the same line which passes to the west of Lassen Peak, a low arch in the older rocks comes out from under the lavas and crosses Pit River into the Klamath Mountains about 20 miles northeast of Redding. This line of displacement appears to be the one connected with the main crest of the Sierra Nevada, and its influence was felt in the Klamath Mountains.

[a] Bull. U. S. Geol. Survey No. 33, 1886, p. 13; Eighth Ann. Rept. U. S. Geol. Survey, pt. 1, 1889, p. 426.

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The length of this faulted belt (shown in Pl. I) from Lake Tahoe to beyond Spanish Peak is over 50 miles, and to Pit River nearly as far again. Though a definite fault line can not be traced all the way, there are places where it is evident. In the Lake Tahoe region, as shown by Lindgren, the faulting on this line occurred chiefly, if not wholly, in the early Cretaceous, but in Mohawk Valley and farther northward the faulting appears to have been chiefly, if not wholly, later than the gravels. The arch, which in the Redding folio is called the Copper City arch, is bordered by fossiliferous rocks which show it to have been formed after the Chico and before the Ione. It is likely, therefore, that the early Cretaceous movement which Lindgren recognized about Lake Tahoe reached the Klamath Mountains about the close of the Cretaceous, but that the greatest amount of displacement along that line in the north end of the Sierras took place after the earlier gravel period.

INDIAN VALLEY FAULT.

Having traced the Honey Lake fault from its north end, where it passes into a monoclinal fold, southeast to the neighborhood of Reno, and the Mohawk Valley fault from Lake Tahoe to the lavas of Lassen Peak and beyond to the Klamath Mountains, let us turn our attention to the line of faulting that lies between the two already noted.

Lindgren has traced a fault from the eastern side of Lake Tahoe northwest across the Truckee into the divide which bounds Sierra Valley on the south. The divide is of volcanic rocks, which Lindgren regards as younger than the fault and which obscure its topographic features. No definite trace of the fault was seen about Sierra Valley, though it may cross in the vicinity of Loyalton and Beckwith, for continuing northwest beyond Sierra Valley we come to Grizzly Valley, which is in line with Indian Valley, where we find in the strong contrast of the two sides of the valley decided evidence of faulting. On the south side are the bold bluffs of Arlington Heights and Houghs Peak, which expose the ends of a thick series of sediments dipping to the southwest, while on the opposite side beyond the valley is a gentle slope, whose topographic features run beneath the north edge of the valley. The Mounds of Indian Valley are knolls which occur on a spur that runs out under the valley. The knolls are sufficiently prominent to rise above the floor of the valley. They are completely surrounded by alluvium, but clearly belong to the spur on the adjacent side of the valley and show that the deep side of the valley is on the south, under the prominent bluffs. The fault is a short one between Taylorsville and Crescent Mills and possibly around to Greenville. The amount of displacement is small. No definite trace of this fault has been found in the canyon of Indian Creek above Taylorsville, where the effects of the Taylorsville reverse fault are in evi-

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dence. The absence of the Arlington beds on the metarhyolite north of the valley, as explained on page 100, is in large measure due to pre-Jurassic erosion. The Indian Valley fault is normal, like that of Honey Lake and Mohawk Valley, and is not to be confused with the Taylorsville reverse fault of the same region.

Northwest of Indian Valley, at the lower end of Big Meadows and Mountain Meadows, the rocks of the Taylorsville region pass beneath the cover of Miocene lavas from the volcanic center about Lassen Peak. North of Prattville, along the northeast edge of Big Meadows, there is a prominent lava bluff due to faulting. Along Rock Creek and also along Warner Creek of the same region, as shown in Pl. I, similar bluffs occur, all approximately parallel and facing the southwest. They are due to faults and have been traced about a dozen miles running nearly N. 30° W. in line with the faulted belt we have traced from Lake Tahoe by way of Grizzly and Indian valleys. Continuing to the northwest, the same line passes east of Lassen Peak in the vicinity of the Snag Lake cinder cone to the prominent fault scarp known as Hat Creek Hill. It faces the southwest. The throw at the south end is over 600 feet, but it decreases to the northwest, and the fault continues for over 20 miles to near Pit River.

The faults of the Indian Valley belt in the Lassen Peak region are remarkable not only for their extent, but also from the fact that they have the downthrow on the southwest side and are of post-Miocene age.

Along Indian Valley the fault may be of about the same age, but the throw is in the opposite direction. In the vicinity of Lake Tahoe, as Lindgren has shown, there was little or no movement at the close of the Miocene. The faulting in that region occurred in the early Cretaceous, with the downthrow on the southwest, similar to that in the Lassen Peak region and the reverse of that in Indian Valley.

GEOLOGIC HISTORY OF TAYLORSVILLE REGION.

PRE-SILURIAN.

What was happening in the Sierra Nevada region during the long eons of the early geologic time is not yet fully made out. The record is fragmentary and complex. During Cambrian time it appears[a] that a mountain range may have occupied approximately the position of the Sierras and limited on the west the thick deposits of Cambrian strata laid down in the Great Basin region. Though it is known[b] that Cambrian strata extend into the Sierra Nevada west of Mono Lake, they do not outcrop in the Taylorsville region, where all the rocks are of later age.

[a] Bull. U. S. Geol. Survey No. 208, 1903, p. 218.
[b] Bull. U. S. Geol. Survey No. 81, 1891, p. 364.

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The earliest scene drawn directly from the records of the Taylorsville region is one of decided volcanic activity, during which the metarhyolite found its way to the surface, but the extent of the volcanic eruptions, whether on land or on sea, and their exact geologic date are matters of conjecture, except that they are older than the adjacent Silurian strata.

SILURIAN.

The Silurian record began over the northern end of the Sierra on the sea floor with the deposition of fine sand and occasional pebbles of the underlying metarhyolite. Layers of dark mud were formed in places containing numerous sponge spicules, such as are found in the Grizzly quartzite, to register the life of the time. Conditions changed somewhat, and corals became abundant with other forms of organisms having calcareous shells. By their accumulation local lenses of limestone were formed, whose fossils indicate the horizon of the Niagara. The occurrence of similar fossils near Eureka, Nev., suggests direct water connection with the great water body which in Silurian time occupied the central part of the United States. The general absence of this limestone on the Pacific coast except in the Taylorsville region may indicate dry land in that region during the Silurian.

DEVONIAN.

Judging from the small size of the limestone lentils, the epoch of their development was brief. Then came changes which involved elevation, exposing parts of the Grizzly quartzite to erosion, but the Taylorsville region appears to have remained much of the time beneath the sea and to have received the conglomerates, sandstones, shales, and cherts of the Taylorsville formation. The pebbles of lava contained in the fine conglomerate at the base of the formation testify to pre-Devonian volcanic activity, including such forms as the metarhyolite, a type which occurs near the same horizon in the Redding region also. The records of Devonian life are obscure or absent in the Taylorsville region, but to the northwest in the Redding region they are abundant. The sea teemed with corals, and the middle Devonian limestone of the Klamath Mountain region is locally full of them. But the record of the Devonian period in the Sierra Nevada, though much fuller than that of the Silurian, is far from complete. The Devonian period was brought to a close by an uplift which exposed the Devonian sediments locally to erosion.

CARBONIFEROUS.

The Carboniferous opened with the northern part of California beneath the sea, receiving deposits derived largely from the erosion of Devonian strata, upon which the Carboniferous strata were laid down unconformably. The shore was not far off, for many fossil-

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iferous limestone pebbles, such as are easily destroyed, were preserved in the conglomerates of the lower Carboniferous of the Klamath Mountains. On the northern end of the Sierra the deposits were finer, composed chiefly of fine shale and sandstones, making up the Arlington formation, succeeded by the siliceous beds of Houghs Peak, with an occasional conglomerate. Then came an epoch of vigorous volcanic activity whose products are widespread. At this time the volcanic tuffs and flows of the Taylor meta-andesite were erupted, and volcanoes were active in the Sierra south of the fortieth parallel[a] as well as in the Redding region[b] of the Klamath Mountains. With the decadence of volcanic activity conditions favorable to the formation of limestone came in and heavy bodies of limestone locally full of fossils were formed throughout the Sierra and the Klamath Mountains. Toward the end of the Carboniferous volcanic action again became vigorous, resulting in the eruption of the Reeve and Kettle meta-andesites, but small lenses of limestone continued to be formed in places to the end of the period, which was brought to a close by an uplift in the Taylorsville region. This uplift in the Sierra Nevada region corresponds approximately to that of the Mississippi Valley and the eastern portion of the United States, where the Appalachian Mountains were formed and the ocean in large measure finally excluded from the Mississippi Valley. In the Sierra it appears to have been accompanied by considerable deformation and metamorphism and possibly erosion before the deposition of Triassic began, for the Paleozoic strata are decidedly more compressed and altered than those of Mesozoic age in the same region,[c] and the two are unconformable. As one of the results consequent upon the deformation of the Taylorsville region, the Taylorsville fault was formed and rhyolite was brought to the surface to receive the Triassic and Jurassic deposits laid down upon it.

TRIASSIC.

During the early Triassic the Taylorsville region appears to have been dry land, but to the northwest in the Redding region the sea prevailed, receiving upon its floor a thick deposit of lavas and tuffs interstratified with and succeeded by shales and thin sandstones of the Pit formation, which does not occur in the Taylorsville region. The northern end of the Sierra subsided, but without great deformation, at the close of Pit time, and the sea again covered a large part if not the whole of the Sierra Nevada. Coiled forms of cephalopods (ammonites) were abundant and large swimming reptiles common. Their remains spread upon the sea floor became entombed in the

[a] Mother Lode District folio (No. 63), Geologic Atlas U. S., U. S. Geol. Survey, 1900, p. 4.
[b] Redding folio (No. 138), Geologic Atlas U. S., U. S. Geol. Survey, 1906, p. 10.
[c] Lindgren and Turner, in gold belt folios.

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Hosselkus limestone. On top of the limestone the dark calcareous mud of the Swearinger slate and, in the Redding region, the Brock shale were laid down over a wide stretch along the Pacific coast from California to Alaska during an epoch which, like that of the Hosselkus limestone, was free from volcanic activity.

JURASSIC.

The Triassic was closed and the Jurassic initiated by small changes of level accompanied by a recurrence of volcanic activity, but all the while most of northern California remained beneath the sea, and the unconformity between the Triassic and the Jurassic is not great. In the Taylorsville region the earliest Jurassic deposits occur in the Trail beds of fresh or brackish water origin. These are of limited extent, for at the same time in the Redding region marine deposits were in progress. In the next succeeding epoch, when the Hardgrave sandstone was deposited, the sea covered the Taylorsville region, western Nevada, and much of eastern Oregon, which continued submerged until near the close of the Jurassic.

Though they were quiescent epochs during which the Hardgrave sandstone, Thompson limestone, and Mormon sandstone were formed, the Jurassic was a period of recurrent volcanic activity, which spread the Fant and Hull meta-andesites upon the surface and furnished a source for much of the material of which the Jurassic strata of the Taylorsville region are composed.

The fauna of the Foreman beds, which is the youngest of the Jurassic in the Taylorsville region, has not yet been studied by a paleontologist in the field, but from all that is known of it thus far its discovery has not changed the order of relative age published by Professor Hyatt,[a] in which he regards the Mariposa formation as younger than those found in the Taylorsville region.

The *Aucella* fauna in the Mariposa beds is limited in the Sierra to the lower portion of its western slope. A thick deposit of slates like those of the Mariposa has been reported by King[b] in western Nevada, but no fossils have yet been found in them to confirm the correlation. The Mariposa contains many conglomerates, and according to Lindgren[c] was laid down in "immediate proximity of the shore line." Its absence east of the main crest in the Sierra is probably due to an uplift at the close of the Taylorsville Jurassic, excluding the sea from that region. Volcanic eruptions on the west slope continued during the Mariposa.

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[a] Bull. Geol. Soc. America, vol. 5, 1894, p. 413.

[b] U. S. Geol. Explor. 40th Parallel, vol. 1, 1878, p. 395.

[c] Colfax folio (No. 66), Geologic Atlas U. S., U. S. Geol. Survey, 1900, p. 3.

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EARLY CRETACEOUS (SHASTA).

The Jurassic was closed and the Cretaceous initiated by a profound compression of the rocks of the Sierra Nevada, folding and crushing them and converting the finer late Jurassic sediments, the Mariposa, into slates. In the Taylorsville region the Jurassic was completely overturned and then faulted by a later movement along the plane of the Taylorsville overthrust. The vast masses, batholiths of granitic and dioritic rocks, as well as many dikes and smaller bodies of various igneous rocks, which form so large a part of the Sierra Nevada, were intruded mainly in connection with the great compression and upbuilding of the range about the beginning of the Cretaceous, and many of the older igneous rocks and sediments were converted into schists along the borders of the batholiths.

The compression, intrusion, and uplift affected not only the region of the Sierra, but also that of the Great Basin adjoining the Sierra on the east, and at that time perhaps not yet clearly differentiated.

The whole region was above the sea and was vigorously attacked by erosion. In the course of long-continued degradation during the early Cretaceous orographic prominences were removed and the surface reduced to comparatively gentle features. A great thickness of fine deposits accumulated west of the Sierra near the fortieth parallel in the Sacramento Valley. Subsidence was in progress along the coast toward the close of the early Cretaceous, and the sea gradually encroached upon the land, but a differential change of level occurred which resulted in the formation of a thick and extensive conglomerate along the present western border of the Sacramento Valley.

This change appears to have involved the lifting up of the Sierra and Great Basin region until the latter started to collapse and break away from the Sierra by the development of a remarkable series of faults, which mark their eastern limit.

South of latitude 38° 30′ the displacement along the east face of the Sierra appears to have taken place chiefly along one fault line, but north of that latitude there were three principal lines of displacement. Beginning near Lake Tahoe they diverge slightly, and then, becoming approximately parallel, extend northwest with more or less continuity for over 100 miles. Lindgren has shown that these faults in the neighborhood of Lake Tahoe are older than the andesitic flows, and appear to have originated during the early Cretaceous. Much of the displacement occurred at that time, but north of the latitude of Sierra Valley the displacement was later.

LATER CRETACEOUS (CHICO).

During the deposition of the Chico the Sierra region was gradually subsiding and the sea transgressing until it beat upon the western foot of the mountains several hundred feet above the present level

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of the sea. The subsidence and transgression were greatest toward the northern end of the range, but were nowhere profound. The Chico sediments soon became fine and more or less calcareous, indicating gentle slopes upon the land approximating the condition of a peneplain.[a] The Chico closed with an uplift which excluded the sea from northern California.

EOCENE.

The uplift at the opening of the Eocene, though small, was accompanied by considerable deformation, resulting locally in a more or less distinct unconformity, but produced no striking change in the character of the marine sediments succeeding the Chico in middle California and southwestern Oregon. The valleys were deepened as a result and then widened, so that comparatively gentle slopes soon again prevailed. The landscape was one of broad and comparatively shallow valleys, whose divides preserved the gentler features of an earlier (Cretaceous) topography. The rate of disintegration became greater than that of transportation, and a mantle of residuary material rich in vein quartz accumulated upon the surface.

From the abundance of material at hand the streams became overloaded and filled their valleys. The gravels were largely quartzose and auriferous. The sand that reached the mouths of the streams was arkose. This appears to have been the condition of affairs indicated by the coaly deposits and sands which form the lower half of the main mass of auriferous gravels in the Taylorsville region.

Well toward the close of the Eocene the Sierra, in latitude 39° 30′, was elevated and greatly increased the stream grade of Jura River, flowing northward, so that it contributed gravel instead of sand to its delta, and numerous bowlders were carried into its channel. The stream grades of the western slope of the range must have been increased at the same time, but according to Turner their grade was not so great as that of Jura River. That this took place in the Eocene is suggested by the fact that the flora of this early gravel epoch is similar to that of the Eocene of Oregon.

MIOCENE AND PLIOCENE.

The conditions of gravel deposition may have continued in the Jura River region from the latter portion of the Eocene through the greater portion of the Miocene and Pliocene apparently without material change. The stream continued to flow and the estuarine body of water which it entered remained covering the north end of the Sierra throughout the period, and as far as may be judged from the gravels the river grade was not changed essentially.

Before the close of the Miocene the volcanic flows from the crest of the range began. The earliest flows were of rhyolite, which fol-

[a] Lindgren was the first to point out this peneplain (Jour. Geology, vol. 4, 1896, p. 894).

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lowed the lines of drainage and covered the gravels about the head of Jura River. Its eruption is represented by layers of volcanic dust in the main gravel mass on Willards Creek. These were followed after an interval by flows of andesitic and basaltic lava and breccia, which completely filled the upper course of Jura River and changed its drainage. The lower course was left uncovered, but along the Diamond Mountain region and farther northwest flows issued and covered large tracts of the main gravel mass and furnished material for the later gravels formed by the waves of the bordering water body.

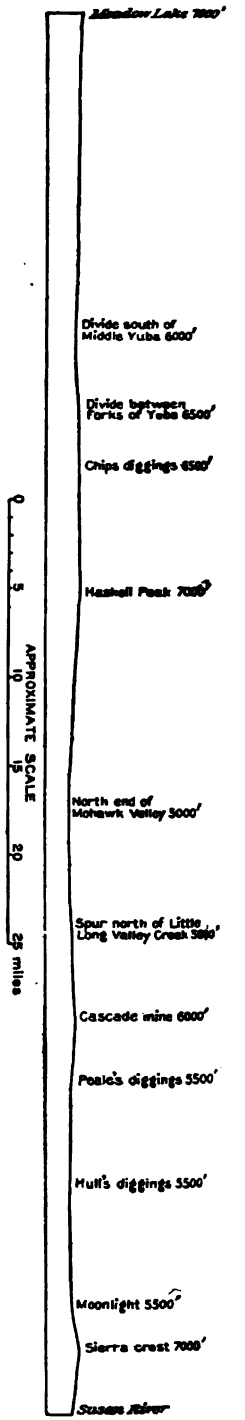

FIG. 12.—Profile of Jura River bed after deformation.

QUATERNARY.

About the close of the Pliocene great changes occurred in the north end of the range. With the adjoining portion of the Great Basin it was uplifted and afterward faulted so as to completely change its topography and drainage. The uplift increased toward the north, for the delta of Jura River was raised from a low altitude to an elevation of 7,000 feet—that is, to nearly as great an altitude as its source. The time of this deformation was subsequent to the volcanic eruptions of its vicinity but contemporaneous with great activity about Lassen Peak, as if the pressure in the one case was relieved by volcanic eruptions and in the other by upheaval.

The upheaval and deformation of the Jura River valley resulted in a complete change of drainage and added to the drainage of the watercourses of the western slope of the range, part of it going to Yuba River, but the greater portion to Middle and North forks of Feather River. The effect of the deformation upon drainage is illustrated in fig. 12 by a general profile along the Jura River bed, omitting the later effects of erosion. The ancient river bed descends from 7,000 feet

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near Meadow Lake to 6,000 feet where drained by the forks of Yuba River, and rises again to 7,000 feet in Haskell Peak. Crossing Mohawk Valley fault it descends to 5,000 feet where drained by Middle Fork of Feather River, but again rises to 6,000 feet at the Cascade mine, from which there is a slight descent to Peale diggings and Moonlight drained by North Fork of Feather River. Here the gravels are decidedly lithified and arch over the eastern block of the Sierra to Susan Creek of the Great Basin region.

The deformation probably began on the east, turning the water westward, and appears to have been very gradual, permitting the forks of Feather River to maintain their courses and cut deep canyons directly across the rising crests of the range. Small temporary lakes may have been formed, but they were not extensive and were soon filled up, forming fertile valleys, of which Indian Valley is an example.

ECONOMIC GEOLOGY.

HISTORY.

During the great gold excitement in California prospectors found their way into the depths of the forest-clad mountains about Indian Valley as early as 1850. The "Bullion ledge," a short distance northwest of Greenville, was discovered the next year and many locations followed, so that within ten years Greenville became an active mining center. Gold was the primary object of search, but the discovery of rich copper ores in 1865 led to the erection of a small furnace, which maintained a sporadic activity for four years.

Though no great mines have been developed about Indian Valley, between forty and fifty small ones have at various times contributed to a total output of over $7,700,000. The values are almost wholly in gold, with a little silver and less copper. Iron ore, coal, building stone, and mineral springs, although present, have not yet become sources of revenue. There are now many active prospects in the region, but scarcely half a dozen paying mines.

On the accompanying sectional map of the Indian Valley region (Pl. V) Mr. Arthur Keddie located the surveyed mining claims of the following list in 1904, and I have added references to the prospects, mines, and ores. The claims are more or less distinctly grouped in two belts, the Crescent Mills belt and the Genesee belt.

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List of mining claims in Indian Valley.

T. 25 N., Rs. 9, 10, and 11 E.:

1. Bridge Q. M.
2. Shoo Fly Q. M.
3. Golden Age Q. M.
4. Golden Era Q. M.
5. Rising Sun Q. M.
6. Golden Dawn Q. M.
7. Golden Coin Q. M.
8. Greenwood Q. M.
9. Jennie Veamans Q. M.
10. Kismet Q. M.
11. Mirabile Visu Q. M.
12. Plumas Grizzly Q. M.
13. Queenie Q. M.
14. Fiesta De Oro Q. M.
15. Camp Compton Q. M.
16. Camille Q. M.
17. Hayward Q. M.
18. Rock Taylor Q. M.
19. King Solomon Annex Q. M.
20. Grand Prize Annex Q. M.
21. Genesee Q. M.
22. Italia Q. M.
23. Queen of Sheba Q. M.
24. Lodi Q. M.
25. Pilot Q. M.
26. Barney Tutt Q. M.
27. Green Ledge Q. M.
28. Queen of Genesee Q. M.
29. Copper Queen Q. M.
30. Centennial Q. M.
31. Centennial South Ex. Q. M.
32. Black Bear Q. M.
33. Brown Bear Q. M.
34. Grizzly Bear Q. M.
35. Polar Bear Q. M.
36. Cinnamon Bear Q. M.
37. Grizzly Q. M.
38. Bear Q. M.
39. Plano Q. M.
40. Peacock Q. M.
41. Ingo Q. M.
42. Copper Bell Q. M.
43. Copper Queen Q. M.
44. Morning Star Q. M.
45. Limbo Q. M.
46. Evening Star Q. M.
47. Reno Q. M.
48. Fossil Q. M.
49. Reward Q. M.
50. Beckwith Q. M.

T. 26 N., Rs. 9 and 10 E.:

1. Centennial Q. M.
2. New York P. C.
3. Kennebec Q. M.
4. Plow Boy Q. M.
5. New York Q. M.
6. Antelope Q. M.
7. Hong Kong Q. M.
8. Dewey Q. M.
9. Johnny Bull Q. M.
10. Bird Q. M.
11. Summit Q. M.
12. W. Pacific Q. M.
13. Pacific Q. M.
14. Drury Q. M.
15. Arctic Q. M.
16. Phoenix Q. M.
17. East Phoenix Q. M.
18. Sunrise Q. M.
19. Sunset Q. M.
20. Arcadian Q. M.
21. Brooklyn Q. M.
22. Comstock Q. M.
23. Dominion Q. M.
24. Union Q. M.
25. Blaine Q. M.
26. Indian Valley Q. M.
27. Arctic Q. M.
28. Summit Q. M.
29. Atlantic Q. M.
30. Hibernia Q. M.
31. Pacific Q. M.
32. Crown Point Q. M.
33. Prospect Q. M.
34. Standart Q. M.
35. Brewster Q. M.
36. Valentine Q. M.
37. Robinson Q. M.
38. Eclipse Q. M.
39. Altona Q. M.
40. Emerald Q. M.
41. Arid Q. M.
42. Lizzie Q. M.
43. Jackson Q. M.
44. Tunnel Q. M.
45. Monroe Q. M.
46. Empire Q. M.
47. Ruby Q. M.
48. Brilliant Q. M.
49. North Star Q. M.
50. Susan Jane Q. M.

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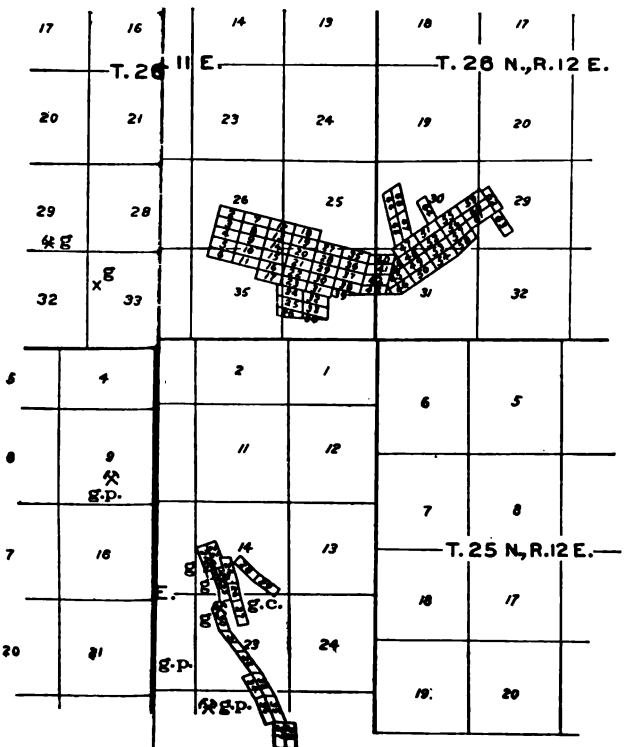

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T. 26 N., Rs. 9 and 10 E.—Continued.
51. Miller Q. M.
52. Cole Q. M.
53. Crescent Q. M.
54. Pet Q. M.
55. Plumas Q. M.
56. California No. 1 Q. M.
57. California No. 3 Q. M.
58. California No. 4 Q. M.
59. California No. 2 Q. M.
60. Palmyra Q. M.

T. 26 N., Rs. 11 and 12 E.:
1. Hull P. C.
2. Hornfel Q. M.
3. Jura Q. M.
4. Laura Q. M.
5. Lucy Q. M.
6. Omega Q. M.
7. Glass Q. M.
8. Main Q. M.
9. Wisconsin Q. M.
10. Climax Q. M.
11. Index Q. M.
12. Jupiter Q. M.
13. Mars Q. M.
14. Signal Q. M.
15. Cherokee Q. M.
16. Hopeful Q. M.
17. Gage Q. M.
18. Venus Q. M.
19. Summit Q. M.
20. Empire Q. M.
21. Locust Q. M.
22. Wonder Q. M.
23. Homestake Q. M.
24. McKinley Q. M.
25. Lincoln Q. M.
26. Garfield Q. M.
27. Queen Q. M.
28. Hammoth Q. M.
29. Williams Q. M.
30. Jessie Q. M.
31. Wide Awake Q. M.
32. Roosevelt Q. M.
33. Washington Q. M.
34. Perkins Q. M.
35. Butte Q. M.
36. Nellie Q. M.
37. Timey Q. M.
38. Rose Q. M.
39. Slim Jim Q. M.
40. Clipper Q. M.
41. Congress Q. M.

T. 26 N., Rs. 11 and 12 E.—Continued.
42. Nome Q. M.
43. Isabelle Q. M.
44. Libby Q. M.
45. Emma Q. M.
46. Molly Q. M.
47. Cooksey Q. M.
48. Chico Q. M.
49. Duncan Q. M.
50. Dome Q. M.
51. Calnan Q. M.
52. Carbonate Q. M.
53. Chondrodite Q. M.
54. Castle Q. M.
55. Jennie Q. M.
56. Cascade Q. M.
57. Cabaritic Q. M.
58. Columbine Q. M.
59. Clasper Q. M.
60. Phonolite Q. M.
61. Colorado Q. M.
62. Crown Q. M.
63. Bond Q. M.
64. Outcrop Q. M.
65. Arizona Q. M.
66. Columbia Q. M.
67. Lyddite Q. M.
68. Jeanette Q. M.
69. Bonanza Q. M.
70. Bonanza No. 2 Q. M.
71. Taylor Diggings Q. M.

T. 27 N., Rs. 10 and 11 E.:
1. Engles Copper Mine No. 3.
2. Engles Copper Mine No. 2.
3. Lucky S No. 2 Q. M.
4. Cadmus P. C.
5. Lucky S Q. M.
6. Sheep Herder Q. M.
7. Moonlight Q. M.
8. Wasp Q. M.
9. Grant Q. M.
10. Hulsman Q. M.
11. Sherman Q. M.
12. Oregon Q. M.
13. Olympia Q. M.
14. Davenport Q. M.
15. Edward Q. M.
17. Sidehill Q. M.
18. Sperm Q. M.
19. Oak Q. M.
20. Shough Q. M.
21. Gentle Annie Q. M.
22. Cabin Q. M.

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T. 27 N., Rs. 10 and 11 E.—Continued.
23. Ridge Q. M.
24. No Wonder Q. M
25. Dexter Q. M.
26. Live Oak Q. M.
27. Fair View Q. M.
28. Stone Point Q. M.
29. Fritz Q. M.
30. Big Spring Q. M.
31. Big Boo Q. M.
32. Belmont Q. M.
33. Claremont Q. M.
34. Vermont Q. M.
35. Palo Cedar Q. M.

T. 27 N., Rs. 10 and 11 E.—Continued.
36. Grant Q. M.
37. Crystal Q. M.
38. Chaune Q. M.
39. Indian Valley Silver Mine.
40. Indian Valley Silver Mine.

T. 28 N., R. 11 E.:
1. North Star Q. M.
2. St. Paul Q. M.
3. Red Ocher Q. M.
4. Sunset Q. M.
5. Talbott Q. M.
6. Jackson Q. M.
7. Yellow Ocher Q. M.

DEVELOPMENT IN THE CRESCENT MILLS BELT.

The principal producing mines of the region have been the Crescent Mills, Green Mountain, Indian Valley, and McGill-Standart, all of which, with many others of less importance, lie in the Crescent Mills mining belt, which extends from the neighborhood of Taylorsville north 50° west through the Crescent Mills and Greenville districts to Wolf Creek, a distance of about 15 miles, with a width of a little over a mile. In the Crescent Mills belt in October, 1904, there were but 2 producing mines, with 1 quartz mill and 2 arrastres.

DEVELOPMENT IN THE GENESEE BELT.

The most continuous activity of the region has been along Wards Creek, on the border of Genesee Valley, where the Gruss mine has been in operation for over twenty years. Near by is the Five Bear mine, and across Genesee Valley is the Cosmopolitan, from which most of the ore was obtained years ago for the Coppertown furnace. Beyond are the Regal, Engel, and finally, in Lights Canyon, the Superior mine, where a body of bornite and chalcopyrite approximately 60 feet long, 40 feet wide, and 3 feet thick has been removed. These mines and several smaller ones lie in the Genesee mining belt, which extends from Wards Creek north 22° west to Lights Canyon, a distance of about 15 miles. While conservative estimates place the total production of the Crescent Mills belt at $6,650,000, that of the Genesee belt has been estimated at $450,000. In 1904 in the Genesee belt there were 5 mines active, with 2 stamp mills and 3 arrastres.

GEOLOGY OF CRESCENT MILLS BELT OF MINES.

The Crescent Mills mining belt has in it two long, narrow masses of granodiorite, one, southwest of Taylorsville, cutting the Paleozoic sediments; the other, between Crescent Mills and Greenville, cutting the quartz porphyries of that district. The metalliferous deposits are confined chiefly, but not wholly, to the igneous rocks, and in none

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of the cases examined are they definite contact deposits such as occur in a portion of the Genesee belt. The deposits throughout the Crescent Mills belt are in more or less well-defined quartz veins running generally parallel to the course of the belt, but in a few cases there are small veins nearly at right angles to the others. The ore is auriferous pyrite, sometimes in small bodies but generally disseminated in the narrow strip of sheared rock of the partially formed vein in which there is usually some quartz. The pyrite is nearly always changed to limonite, setting the gold free and staining the indistinct vein as well as its walls. One of the best defined and most complete quartz veins of the Crescent Mills belt occurs in the Premium mine. It is vertical, about 2 feet in thickness, and cuts granodiorite.

In the Green Mountain mine one subordinate vein carries a small amount of chalcopyrite, but in general copper is absent in the belt except at the old Pettinger mine, two-thirds of a mile south of Taylorsville, where a small imperfect vein in the Taylorsville slate is impregnated with carbonates of copper, sometimes blue but generally green.

An exceptional deposit for the Crescent Mills belt, and indeed for the whole region, is a mass of pyrrhotite a mile and a half nearly south of Taylorsville. It lies in a narrow strip of sheared sandstone running north and south near the horizon of the Montgomery limestone, but the largest body, about 10 feet in thickness, is at a point where the sheared sediments end against serpentine. The pyrrhotite was tested for nickel by Hillebrand, but none was found.

GEOLOGY OF THE GENESEE BELT OF MINES.

The Genesee mining belt follows approximately the northeastern limit of the Mesozoic and Paleozoic sediments where they come in contact with the granodiorite and the Kettle meta-andesite. The deposits are variable; some are more or less complete veins following narrow belts along which the rock has been crushed and sheared; others follow the line of contact bounding the granodiorite. In some deposits the ore is auriferous quartz and limonite, but in others the ore is chiefly bornite, chalcopyrite, chalcocite, or copper carbonates. Quartz is the most common gangue mineral, but in one case barite appears and in another a green mineral like actinolite.

The Gruss mine, on Wards Creek, is on both sides of the contact between the Kettle meta-andesite and slaty shale of the Robinson formation. In the shale the partially formed veins follow narrow shear zones, in which there is some auriferous quartz associated with limonite that deeply stains the richest portions of the crushed mass. The adjacent meta-andesite is often decidedly slaty and its ores are chiefly chalcopyrite or bornite, with copper carbonates near the surface.

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The rocks along the contact are much sheared and apparently somewhat richer than those on either side. No characteristic contact minerals were observed to suggest that ores in this case were originally contact deposits modified after the development of the slaty cleavage.

The Five Bear mine in the Robinson slate is much like the Gruss, but the Green Ledge, Pilot, and others in the Kettle meta-andesite have small veins of quartz with bornite and some chalcocite. The veins are generally less than 5 inches in thickness.

The Cosmopolitan mine is on the contact of the granodiorite with the Hosselkus limestone and Swearinger slate. The ore is bornite and chalcopyrite, forming solid bodies up to 15 feet in thickness, with greater dimensions in the plane of contact, along which other smaller bodies of the same ore occur. On the surface the contact is marked by masses of garnet and epidote which were not seen beneath, but in the Duncan mine the garnet and epidote are associated with the ore.

The Bluebell mine is in the Hosselkus limestone near the contact, and from one of its shafts some tons of carbonate of copper have been brought up in connection with cave breccia, suggesting a secondary deposit within the limestone. A small vein of barite occurs in altered andesites at the old Indian Valley silver mine, about a mile southwest of Lucky S mine, and locally contains traces of copper ore.

Near the northwestern end of the Genesee belt is the Superior mine, in which the gangue of the bornite is a green fibrous mineral like actinolite. A number of parallel vertical veins of this mineral are well exposed in the open cut and contain disseminated particles and nodules of bornite. The larger ore bodies are free from gangue. The wall rock, which is fine-grained granodiorite, is the same on both sides and the veins are sharply defined.

AURIFEROUS GRAVELS.

Development.—In the Taylorsville region modern stream beds have been mined in Lights Canyon and on Indian Creek above Flournoy as well as below Arlington Bridge. The total yield of these modern gravels is near $10,000 annually.

About the head of Lights Creek, Mountain Meadows, and Moonlight ancient gravels have been mined irregularly in a small way for over twenty years, and the total yield, according to a conservative estimate, is nearly $500,000.

Kinds of gravel.—The auriferous gravels which have been mined about Indian Valley are of two kinds—(1) the gravels of the present stream beds and terraces near them, and (2) the gravels of ancient streams, or high gravels like those of the Taylor diggings on the mountain summits far above the streams of to-day, composed generally of well-rounded waterworn gravel.

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Auriferous gravels of present streams.—The gravels of the present stream beds and their terraces have been mined at a number of points in the region, especially along the upper courses of the streams where the grade is sufficient to prevent the deposition of finer material such as fills Indian Valley proper, North Arm, and Genesee Valley.

Indian Creek heads about Diamond Mountain and Thompson Peak on the eastern crest of the Sierra Nevada in a large area of high gravels, and has doubtless concentrated whatever gold there may have been in the small amount of gravel which has been washed away. Judging, however, from present activity and recent output, the part of Indian Creek east of Genesee Valley does not hold out especially promising prospects, but this can not be taken as conclusive. The record of a greater activity years ago is not available.

Lower down on Indian Creek beyond Indian Valley, near Shoo Fly Bridge, gravel on one of the benches is worked by water taken out at the narrows and having a fall of nearly 100 feet. The excavation is but little above the stream level and has been carried on in a small way by R. Martin for a number of years. Within this portion of the quadrangle there has been no hydraulic mining for several years, but a few miles farther west, on Soda Creek, Rush Creek, and North Fork of Feather River, hydraulic and placer mining have been carried on extensively and profitably for many years.

Placer mining has been carried on along the upper course of Wolf Creek, Cooks Canyon, and several other small streams, but the most effective and persistent efforts have been made on Lights Creek and Little Grizzly Creek, just beyond the limit of the Indian Valley special quadrangle.

On Lights Creek, Ruffa, the Chatfield Brothers, and Peters work for several months every year with water under about 100 feet pressure and one or two giants each, but the amount of débris removed is small.

On Little Grizzly Creek, one of the strongest streams of the region, the work is done on a somewhat larger scale during the summer in the present stream bed, where large bowlders are encountered. In the winter the terraces from 100 to 200 feet above the stream are worked, and in the same region at a much greater elevation is the Cascade hydraulic mine described by Turner in the Downieville folio.

The entire annual yield of the placer mines within and bordering on the Indian Valley quadrangle is probably somewhat less than $10,000.

Auriferous gravels of ancient streams.—The distribution of the auriferous gravels of ancient streams in the Taylorsville region is fully shown on Pls. II and III. They are mined at a number of points, especially near the border of Moonlight, at the southeastern head of Mountain Meadows, and in Cooks Canyon, where Evans, Davis, Smith, and others have operated a month or more nearly

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every year for twenty years, but the work is confined to the lower edges of the gravels, which range from an altitude of 5,000 feet on the west and north to 7,000 feet at the southeast about Diamond Mountain, on the crest of the Sierra Nevada. As the gravels rest upon the summits, it is almost impossible to obtain water in quantities sufficient for ordinary mining even a few days or weeks each year.

In connection with the ancient auriferous gravels certain residual deposits should be noticed in which the débris was not waterworn nor at any time in any proper sense a part of a stream bed. The débris is simply the material derived from the disintegration of the bed rock in place. Where rocks contain veins rich in native gold, the gold liberated by disintegration lodges near by unless removed by erosion.

A third of a mile northwest of Round Valley Reservoir a placer mine on the gentle slope toward the reservoir is said upon good authority to have yielded $150,000 some years ago. The placer mine covered the northern extension of the veins from the Standart-McGill mine on the adjacent slope, and its richness is to be attributed to the residual material from the veins.

Another example of the same kind was in the placer mine of Mr. Davis, who washed the soil from the slate hill where the Gruss mine of Genesee is now located, and where auriferous veins were discovered which yielded about $25,000.

Several years ago, on the western slope of the Moonlight branch of West Fork of Lights Creek, a small but rich placer was discovered and worked for a little while. The material, though largely residual, contains some gravel and lies close to the bottom border of the great body of gravel about Moonlight. The gravel of that region rests on residual material, and it is possible that the local richness is derived from the gravels removed in the process of erosion.

DEPOSITS OF IRON ORE.

Although iron is not mined in the Indian Valley region, there are several deposits of sufficient importance to deserve mention, and at some future time they may be utilized. The most promising is at the southern border of Moonlight, in a broad valley at an elevation of 5,600 feet, 11 miles north of Taylorsville, where an area of about 2 acres occurs having red soil strewn with black chunks of hematite and with some magnetite. Some of the fragments are 2 feet in diameter. No excavations have been made, but the ore on the surface and the color of the soil indicate a considerable body of iron ore beneath.

About a third of a mile west of this locality a small opening exposes a mass of hematite, in part breccia, over 4 feet thick. It strikes

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nearly east and west approximately in line with the area noted above and dips about 45° to the south.

A few degrees west of south from the 2-acre area there are a number of small pits and fragments of iron ore in line to an old opening made by Hulsman, which exposes a veinlike mass of magnetite and hematite. Some of the fragments have magnetic polarity; others are not magnetic at all. The opening is only about 10 feet deep and the ore is said to run out at that depth. It is possible that there are two lines of iron-ore deposits, one nearly north and south and the other approximately at right angles. The two lines appear to meet in the 2-acre area.

Red chert is exposed at a number of points in the Indian Valley region, and it is not yet known to how many horizons it may belong. With it is always associated more or less hematite, so that the specimens frequently resemble the jasper iron ore of the famous Marquette region in Michigan.

One of the best outcrops of this kind is in the summit of Houghs Peak, but the amount of hematite exposed is always small.

An exceptional and perhaps the most interesting mineral deposit rich in iron in the Taylorsville region is the mass of pyrrhotite a mile and a half south of Taylorsville. It is briefly described on page 115, in connection with the Crescent Mills belt.

DEPOSITS OF COAL.

In the Taylor gravel diggings a few years ago a bed of coal was laid bare and at the time attracted attention. The bed is about 5 feet thick, lies nearly flat beneath the auriferous gravels to which it belongs, and rests directly upon the upturned edges of Jurassic sandstone. On the north side it is cut off by a fault and ends abruptly against the sandstone. Southward beneath the gravel its extent is unknown, but can not be great. About a ton of coal has been mined for blacksmithing, but no definite local demand has yet resulted.

Traces of coal were observed also east of Moonlight, near the base of the great deposit of auriferous gravel and sand, and mark an epoch of very gentle slope at the beginning of the auriferous gravel period. None of the coal is of economic value.

MINERAL SPRINGS.

Among the mineral resources of the Indian Valley region are several mineral springs on the main road from Taylorsville to Quincy. A few hundred yards northeast of the Arlington Bridge is an iron spring of moderately cool water containing some free carbon dioxide and carbonate of lime, so that it forms a mound of calcareous tufa deeply stained or completely covered with oxide of iron. Its flow is about 4 quarts per minute, and it is recommended by the people of the vicinity who have used it as good for those having dyspepsia.

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Between Shoo Fly Bridge and Clear Creek, on the Quincy road, are two soda springs. The one near Shoo Fly is clear and cool and rich in carbonic acid, refreshing many a passing traveler; the other is less highly carbonated and has more iron. Both have deposited large masses of calcareous tufa on the steep slopes. Near the Shoo Fly Bridge the tufa looks like an ordinary limestone.

The hot spring near Greenville, said to be locally used for bathing in case of rheumatism, was not examined.

RÉSUMÉ.

The topographic elements of the north end of the Sierra are three fault blocks with prominent escarpments to the east and long, gentle slopes to valleys along their western borders.

There are eighteen sedimentary formations in the Taylorsville region, of which six are Paleozoic, nine Mesozoic, one Tertiary, and two Quaternary. The oldest is Silurian quartzite with some lentils of slate and of limestone, followed in regular order by Devonian slate and a great succession of Carboniferous strata that for convenient consideration may be separated into four formations—Arlington, Shoo Fly, Peale, and Robinson—all of which are characterized more or less fully by fossils. The first three embrace a large part of the strata which form the Calaveras of the gold belt folios.

The Triassic has two formations in the Taylorsville region, one of limestone, the other chiefly of slate, but the Pit formation and volcanic rocks at the base of the Triassic, so extensively developed in the Redding region, do not appear about Taylorsville, where their horizon is represented apparently by a marked unconformity.

The Jurassic is unconformable on the Triassic and is made up of a succession of seven formations, which are characterized for the most part by abundant faunas.

Of the igneous rocks metarhyolite is the oldest. Its effusion probably dates from early in the Silurian, certainly earlier than the time of the Grizzly formation. Volcanoes were especially active at intervals in the Carboniferous, giving rise to three extensive masses of meta-andesite. They were active also in the early Jurassic.

About the close of the Jurassic, in connection with the compression and deformation of the rocks of the Sierra Nevada, the greatest eruptive masses of the region were formed. The rocks differ markedly in type from those of earlier date. While the earlier ones were prevailingly volcanics, effusive, those at the close of the Jurassic were intrusive, some of them coarse granular, like diorite and peridotite, while others were finer grained, forming dikes.

The great structural features developed in the Taylorsville region during the orogenic epoch at the close of the Jurassic are the Grizzly

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Mountains anticline, the Mount Jura syncline, and the Taylorsville fault. The Jurassic strata were completely overturned toward the east and then faulted by an overthrust—the Taylorsville fault—in the same direction.

Following the epoch of igneous intrusion and mountain building which made the Sierra Nevada a prominent range came one of long-continued erosion, for the Sierra Nevada has ever since been dry land, exposed to vigorous degradation. The earlier records of this degradation are not yet clearly made out, but the later ones are contained in the subsequent Cretaceous and Tertiary sediments of the Sacramento Valley.

Though the late Cretaceous sediments lie upon the western base of the Sierra Nevada, they do not form a considerable part of the range. The first post-Jurassic rocks involved in the main body of the northern end of the range are the earlier auriferous gravels.

The long-continued erosion during the Cretaceous, with comparatively little upheaval, reduced the bold orographic features formed at the close of the Jurassic to gentle slopes and gave rise to what Lindgren has designated the Cretaceous peneplain. A small differential uplift of the range incised the old peneplain. In the course of time the valleys were widened and filled with auriferous gravel and finally covered by volcanic flows.

The prevolcanic portion of the auriferous-gravel period is represented on the north end of the range by 1,000 feet of deposits, of which the lower half is chiefly residual sand. This sand originated in the gentle slopes of the region when disintegration exceeded transportation, and the auriferous quartz veins were set free and gradually concentrated by the removal of fine material until the rich quartz gravels of the earliest stream beds now preserved were formed. The prevolcanic portion of the auriferous-gravel period was long, and the drainage of the Taylorsville region at that time was northward, into the water body which then filled the Lassen Peak depression between the Sierra Nevada and the Klamath Mountains and received sediments of the entire period.

The flora of the early auriferous gravels of the Taylorsville region has a number of forms that occur not only in the earlier gravels of the western slope of the Sierra Nevada but also with marine shells of Eocene age in Oregon and support the suggestion made by Lindgren that the earliest prevolcanic auriferous gravels are at least in part of Eocene age.

The condition of low relief prevailed, with but slight changes of level, to the close of the Tertiary, when the Quaternary was initiated by great topographic changes, the consequences of the great uplifting and faulting of the range.

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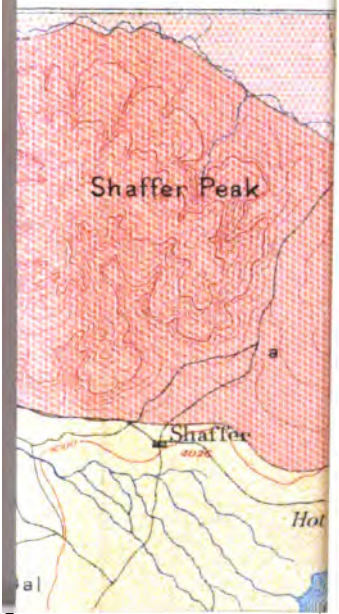

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 354

THE CHIEF COMMERCIAL GRANITES OF MASSACHUSETTS, NEW HAMPSHIRE AND RHODE ISLAND

BY

T. NELSON DALE

WASHINGTON
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CHIEF COMMERCIAL GRANITES OF MASSACHUSETTS, NEW HAMPSHIRE, AND RHODE ISLAND.

By T. Nelson Dale.

INTRODUCTION.

In Bulletin No. 313, published in October, 1907, by the United States Geological Survey, the granites of Maine were described by the writer from both the scientific and the economic standpoint. The design of the present work is to extend the same method of treatment to the granites of greatest economic importance in Massachusetts, New Hampshire, and Rhode Island. These are the granites of Milford, Quincy, Rockport, and Becket (near Chester) in Massachusetts, of Concord, Milford, and Conway in New Hampshire, and of Westerly in Rhode Island. In addition certain granites from Auburn and Sunapee in New Hampshire are incidentally considered. The granites of Monson and Graniteville, in Massachusetts, and of Troy, in New Hampshire, and of several other places in the three States named, will be taken up in a later publication. Bulletin No. 313 contains a scientific discussion of granite adapted to the general reader, and also, in its economic portion, material of general economic interest. For convenience of reference those parts of that bulletin are here republished, but in revised form. In both bulletins some purely scientific matter necessarily appears in the economic part, in the geological summary which prefaces the description of each group of quarries.

The field work upon which this report is based, involving visits to 88 quarries, was done in 1906. The petrographic work necessitated the study of 350 thin sections. The writer is indebted to Dr. Albert Johannsen, of the United States Geological Survey, for critical revision of his determinations of the minerals of these sections, and to Messrs. E. C. Sullivan, George Steiger, and W. T. Schaller, chemists, of the Survey, for determinations of the percentages of lime soluble in hot dilute acetic acid in 23 granites. Miss A. T. Coons, of the Survey, has contributed a chapter of statistics on the granite produced at the centers referred to and in the States named. Prof. Charles Palache, of Harvard University, has consented to the insertion of a

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note on a dike at Quincy. Mr. E. W. Branch, C. E., of Quincy, has allowed the reproduction of his copyrighted map of its quarries. Information as to the general geological relations of the various granites has been obtained from works on local geology by Emerson and Perry, Shaler and Tarr, Sears, Crosby, C. H. Hitchcock, Kemp, and Rice and Gregory. These are quoted or referred to in the section preceding the descriptions of the quarries of each district.

The Rosiwal method of estimating mineral percentages has been applied to all the types of granite described. These types will be found defined and classified, both scientifically and commercially, in the table on pages 211–212, which is followed by a section on their relative commercial values.

The numbers of the specimens described, to which those of the thin sections correspond, are given, so that the descriptions can be verified by consulting the collections at the National Museum. All these specimens have been prepared from blocks selected by the foremen or superintendents.

Such scientific terms as have unavoidably been used are explained in the glossary at the end, where also some of the quarrymen's terms are made intelligible to the general or scientific reader.

The names applied to the various granites in this report are, with a few exceptions, merely local or trade designations. Their employment in this economic bulletin does not affect the standing of any particular name as a geologic formation name.

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PART I.—SCIENTIFIC DISCUSSION.

GENERAL FEATURES.

GRANITE PROPER.

DEFINITION.

Granite, in a general sense, is essentially an entirely crystalline igneous rock, consisting mainly of quartz, potash feldspar, and a feldspar containing both soda and lime, also of a small amount of either white or black mica or both, and sometimes of hornblende, more rarely of augite, or both. Where granite has, subsequent to its crystallization, been subjected to pressure sufficient to produce a parallelism in the arrangement of its minerals—that is, a schistosity—it is no longer a true granite, but a gneiss or granite gneiss; a sedimentary rock, however, in becoming crystalline may resemble a granite gneiss and is called a sedimentary gneiss.

ORIGIN.

Granite is now regarded as the product of the slow cooling and crystallization of molten glasslike matter at a dull-red heat—matter which contained superheated water, and was intruded from below into an overlying mass of rock of sufficient thickness not only to prevent its rapid cooling and its general extrusion at the surface, but also to resist its pressure by its own cohesion and powerfully to compress it by its own gravity. As carbonic acid can be liquefied only under pressure, its presence in liquid form within some of the microscopic cavities in the quartz of granite is alone evidence that the rock was formed under pressure. That the temperature at which granite solidified was comparatively low has been inferred from the fact that it contains minerals which lose their physical properties at temperatures higher than dull-red heat. The relations of the mineral constituents of granite to one another show the order in which they must have crystallized. This order differs from that in which they would crystallize if molten in a dry state, but laboratory experiments have shown that the presence of even a small quantity of water suffices to change that order of crystallization. The presence of superheated water in the formation of granite, inferred from the arrangement of its minerals, and the pressure indicated from a study of the contents of the microscopic cavities of its quartz show that the conditions requisite to its formation included not only the pressure of a great

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overlying mass of rock but also powerful expansive pressure from below. Had this molten matter been extruded at the surface it would have cooled so rapidly that but few of its constituent molecules would have had time to arrange themselves in geometric order. The process of crystallization would have been arrested by the sudden passage of the material into the solid state and the product would have been a volcanic glass somewhat resembling that which forms cliffs in Yellowstone National Park. In granite, however, the mass has cooled slowly enough to permit the complete crystallization of the originally molten glasslike matter, and no unarranged molecules remain.

The overlying rock mass which furnished so large a part of the pressure required to form granite has at many places been removed from it by erosive processes that operated through great stretches of time. Indeed, it is only by the removal of this mass that granite is anywhere naturally exposed. Although this mass may have measured thousands of feet in thickness, its former presence is at some places attested only by a thin capping on the granite or by fragments which the lacerating action of the intruding granite has incorporated into itself.

The lacerating effect of an intrusive eruption and the subsequent erosion of some of the overlying strata have been reproduced experimentally.[a] The conversion of granite itself back into a material which upon cooling under ordinary conditions has proved to be a glass, has been effected in the laboratory, and the chief mineral constituents of granite have been artificially crystallized at high temperature in the presence of water vapor under high pressure, but the conditions requisite for the production of a granitic rock from its chemical constituents have not yet been successfully imitated.

Some granite shows locally a certain alignment of its mica plates and feldspars, due to the flow of the mass while it was in a plastic state—a structure which was probably controlled by the pressure and form of the bordering rock. This "flow structure" should not be confounded with the schistosity which is due to later pressure and which also involves mineral changes and is usually regional rather than local in extent.

The great differences in the grade of texture in granites—the mineral particles ranging from an average diameter of one-fiftieth inch

[a] Howe, Ernest, Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 3, pp. 294-296, Pl. XLIII. Reyer, of the Austrian Geological Survey, has illustrated a granite intrusion by this simple experiment: Upon a table a frame of clay, say 2 inches thick, is constructed about a square piece of board 1 inch thick. After removing the board a mixture of medium thick plaster and red coloring matter is poured into the inclosure. The surface of the red plaster is then sprinkled with a layer of white plaster powder. After making a lens-shaped perforation in the center of the board it is again fitted into the frame and pressed against the red and white layers until the white plaster exudes through the opening, and afterwards the red intrudes the white. The materials are allowed to harden and are then sawn to show the structure. See Reyer, Ed., Tektonik der Granit Ergüsse von Neudeck und Carlsbad, etc. Jahrb. K.-k. geol. Reichsanstalt, vol. 29, 1879, pp. 432-433, fig. 6.

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(0.50 mm.) and even 0.0069 inch (0.175 mm.) to over half an inch—is attributed to differences in the rate of cooling. The portions at the margin of the mass, which cooled rather quickly, crystallized in very small crystals, while the central portions, which cooled more gradually, became coarsely crystalline.

MINERALOGICAL COMPOSITION.

Feldspar is the most conspicuous and generally the most abundant mineral in granite. By its color or colors it usually determines to a large extent the general color of the rock; and by the light which it reflects it causes also its brilliancy. It is easily distinguished from the other constituents by its smooth cleavage surfaces and milky, bluish white, or opalescent, or reddish, brownish, or greenish color. Granite usually contains two kinds of feldspar, the most abundant of which is generally potash feldspar, a silicate of alumina and potash. This occurs in one of two crystal forms, orthoclase or microcline, or in both, which, however, can be distinguished only by means of the microscope. The other feldspar (plagioclase), containing both soda and lime, although it may be of the same color as the potash feldspar, can often be distinguished from it by the very fine parallel lines on its surface. Usually it differs greatly in color from the first. The potash feldspar may be reddish or brownish; the plagioclase may be white or greenish. Under the microscope the soda-lime feldspar can be readily distinguished from the potash feldspar by its behavior in polarized light, which brings out its crystalline structure and indicates its particular variety and approximate chemical composition. A granitic rock that contains the two feldspars in equal proportions is distinguished by a special technical name.

Quartz (silica), the next most abundant constituent, is readily known by its glassy luster, uneven fracture, and brittleness. It may be colorless, bluish, opalescent or amethystine, or smoky. The quartz in the rock determines in some measure its shade. The vitreousness of the quartz greatly affects the granite.

The next most abundant constituent of granite is mica, which is present in two forms—the white (muscovite, or potash mica), essentially a silicate of alumina with potash, soda, and ferrous oxide, and the black (biotite, or magnesia mica), essentially a silicate of alumina with potash, magnesia, and both ferric and ferrous oxide. Granite may contain one or both of these. The dimensions and number of the scales of black mica largely determine the shade of many granites.

Hornblende, a constituent of many granites, although greenish (rarely bluish), may appear as dark as the black mica, but, unlike that mineral, it does not split into scales. Augite and hornblende resemble each other so closely when in minute particles that they can be distinguished only by means of the microscope. Both may occur.

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In addition to these more important minerals, others are usually present in minute or microscopic quantities. Some of these, kaolin, sericite (a potash mica or muscovite), chlorite, epidote, zoisite, and calcite, as well as paragonite (soda mica), which may possibly be present, are the result of chemical changes in the feldspars or the biotite or hornblende and are therefore called "secondary." Others—like zircon, apatite, titanite, rutile, tourmaline, fluorite, garnet, magnetite, molybdenite, ilmenite, pyrite, allanite—are regarded as original "accessory constituents." Calcite also occurs in microscopic quantity as an original mineral of some granites.[a] Of these minor accessories, pyrite (iron disulphide) and calcite (lime carbonate) alone have economic significance, for these may discolor or weaken the stone when dissolved or oxidized on an exposed surface.

The chemists of the United States Geological Survey have treated 10 granites from Maine and 23 from Massachusetts, New Hampshire, and Rhode Island with hot dilute acetic acid and find that the Maine granites contain 0.14 to 0.43 per cent of $CaCO_3$ (lime carbonate) and the others from 0.07 to 0.6 per cent.

During the preparation of the bulletin on Maine granites and of this bulletin the following accessory minerals have been detected: Garnet, zircon, titanite, magnetite, pyrite, molybdenite, fluorite, apatite, allanite, and rutile; also the following secondary minerals: Hematite, limonite, calcite, kaolin, muscovite, paragonite (probably) quartz, hornblende, riebeckite, epidote, and zoisite.

The arrangement of the important minerals in the stone will be described under the heading "Texture."

The percentages of the mineral constituents differ within wide limits in granites from different localities. The percentage of muscovite and of the ferromagnesian minerals (biotite, hornblende, augite) is always small, while that of the feldspar and quartz is large. There is considerable variation in the relative amounts of feldspar and quartz and still more in the amounts of each of the feldspars.

CHEMICAL COMPOSITION.

The chemical composition of granite is of less scientific and economic significance than its mineral composition, for, although chemical analysis shows the percentages of the constituent elements, the process by which these are determined necessarily mingles the elements of several minerals whose proportions vary and whose contribution to the physical properties of the rock differ greatly. When, however, a combination of elements occurs only in one or two of the minerals the chemical analysis serves to corroborate the evidence obtained by microscopic analysis.

[a] See Zirkel, Petrographie, vol. 2, p. 13, and Weinschenk, Abhandl. Math.-phys. Classe, k. Bayer. Akad., vol. 18, p. 730, Pl. V.

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Many analyses of granite have been published, but it will suffice here to give the extremes of the percentages shown by some of the more important of these and to refer the reader to works containing complete analyses.[a] Four analyses of granites from Scotland, Ireland, Italy, and Sweden show the following ranges:[b]

Analyses of European granites.

SiO_2 (silica)	70.60–74.82
Al_2O_3 (alumina)	14.86–16.40
Fe_2O_3 (ferric oxide)	.10– 1.63
FeO (ferrous oxide)	.36– 1.64
MnO (manganese oxide)	.00– .48
MgO (magnesia)	.23– 1.00
CaO (lime)	.89– 2.47
Na_2O (soda)	3.51– 6.12
K_2O (potash)	3.55– 5.10

Ten analyses, made at the laboratory of the United States Geological Survey, of granites from Arizona, California (2), Colorado (4), Maryland, Michigan, and Montana, show the following ranges:[c]

Analyses of American granites.

SiO_2 (silica)	66.68–77.68
Al_2O_3 (alumina)	11.63–16.38
Fe_2O_3 (ferric oxide)	.00– 1.66
FeO (ferrous oxide)	.09– 3.32
MgO (magnesia)	.04– 2.19
CaO (lime)	.12– 4.89
Na_2O (soda)	2.36– 5.16
K_2O (potash)	1.87– 6.50
TiO_2 (titanium dioxide)	.07– .45
P_2O_5 (phosphoric acid)	Trace– .10

The average of 21 analyses of even-grained Georgia granites made by Watson[d] yield the following percentages:

Analyses of Georgia granites.

SiO_2 (silica)	[e]69.97
Al_2O_3 (alumina)	16.63
Fe_2O_3 (ferric oxide)	1.28
CaO (lime)	2.13
MgO (magnesia)	.55
Na_2O (soda)	4.73
K_2O (potash)	4.71

One hundred and thirty-seven analyses of Swedish granites will be found arranged in a continuous table in a recent work of Holmquist.[f]

[a] See Washington, H. S., Prof. Papers U. S. Geol. Survey Nos. 14, 1903, and 28, 1904; also Clarke, F. W., Bull. U. S. Geol. Survey No. 228, 1904.

[b] Geikie, Archibald, Text-book of Geology, 4th ed., vol. 1, London, 1903, p. 207.

[c] See Bull. U. S. Geol. Survey No. 228, p. 54, analysis D; p. 197, analysis D; p. 231, analysis A; p. 232, analysis A; p. 185, analysis B; p. 161, analyses A, C, F; p. 78, analysis A; p. 145, analysis C.

[d] Watson, Thomas L., Bull. Georgia Geol. Survey No. 9–A, 1902, p. 241.

[e] Extremes 68.38–72.56.

[f] Holmquist, P. J., Studien über die Granite von Schweden: Bull. Geol. Inst. Univ. Upsala, VII, Nos. 13 and 14, 1904–5, pp. 77–269. Upsala, 1906.

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It should be noted that in all these analyses most of the lime is to be attributed to the lime-soda feldspar and nearly all the rest of it to apatite (lime phosphate), or to hornblende and augite when these are present.

It is of interest to note in this connection that certain Scotch and Irish granites contain from 1.6 to 2.8 volumes of gas per volume of rock. This gas is inclosed in microscopic cavities within the minerals, and in the Scotch granite consists of carbon, oxygen, hydrogen, and nitrogen in the following combinations and proportions: CO_2, 23.60; CO, 6.45; CH_4, 3.02; N_2, 5.13; H_2, 61.68.[a] These gases are probably present in all granites.

TEXTURE.

Definition.—By the texture of the rock is to be understood those characteristics which are apparent on its surface, or, more exactly, the forms and mutual relations of its minerals as seen without and with a microscope.

Character and grade.—The most important feature of granite is the character of its grain. Some granites are even grained; others contain more or less thinly disseminated and complete crystals of feldspar in a mass of finer, even-grained material—that is, they show what is called porphyritic texture. The next most important feature—perhaps more important—is the relative coarseness or fineness of grain in an even-grained granite. Three grades of texture of this sort may be distinguished: (1) *Coarse*, in which the feldspars generally measure over 1 cm., or two-fifths inch; (2) *medium*, in which they measure under 1 cm. (two-fifths inch) and over 0.5 cm. (one-fifth inch); (3) *fine*, in which they measure under 0.5 cm. (one-fifth inch). In some coarse-grained granites the feldspars measure one or several inches, and in some fine-grained ones all the particles range from 0.25 mm. to 1 mm. (one twenty-fifth inch) in diameter, and some average as low as 0.50 mm., or one-fiftieth inch. Extremely fine ones average 0.175 mm., or about seven one-thousandths inch.

Forms of minerals.—Even without the aid of the microscope it will be noticed that, except in granites of porphyritic texture, the minerals rarely attain their complete crystalline form. They have interfered with one another's growth. It will also be noticed that some of the crystals of feldspar in some granites are surrounded by a border of a different feldspar. Thus a red feldspar may be bordered by a white or greenish one, or vice versa. Either of these may be the potash feldspar and the other a soda-lime feldspar. It will also be noticed that many of the feldspars are not simple incomplete or complete crystals, but "twins," having the cleavage planes in one half at a different angle from those in the other half, so that when held in the sunlight only one half will reflect the light in one position.

[a] Tilden, W. H., Proc. Roy. Soc. London, vol. 60, No. 366, Feb. 20, 1897, pp. 454, 455.

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Arrangement of minerals.—A polished surface of any medium or coarse-grained granite shows that the quartz fills up the spaces between the feldspars—that is, was formed after them—also that both feldspars and quartz inclose particles of mica, etc., which must therefore have crystallized before them. Under the microscope the arrangement of the minerals is found to be such that they must usually have crystallized in the following order: Magnetite, pyrite, apatite, zircon, titanite, hornblende, biotite, muscovite, the feldspars, and, last of all, the quartz. It should be noted, however, that many of the feldspar crystals contain intergrown quartz, so that some of the quartz must therefore have crystallized at the same time as the feldspar. The structure of the potash feldspar in some granites is very intricate, as it contains microscopic intergrowths of a lime-soda feldspar, both having evidently crystallized at the same time or in close alternation. Also, as stated above, the potash feldspar may be rimmed with soda-lime feldspar, or vice versa.

PHYSICAL PROPERTIES.

Granite derives its physical properties from its mineralogical constitution, particularly from its large content of feldspar and quartz, and from its texture. Among these physical properties the most important are weight, cohesiveness, elasticity, flexibility, hardness expansibility, porosity, and vitreousness. Each of these qualities will be taken up in the order in which they are here stated.

Weight.—In order to establish a fixed standard the weight of a rock is compared to that of an equal volume of distilled water. The weight thus determined is called its specific gravity. The specific gravity of granite ranges from 2.593 to 2.731. The average of these extremes is 2.662, which is equivalent to 2 long tons, or 4,480 pounds, to the cubic yard, or about 165 pounds to the cubic foot. Geikie[a] calls attention to the change in the weight of granite when immersed in sea water, as given by Stevenson.[b] A red granite having a specific gravity of 2.71, or 13.2 cubic feet to the ton in air, will in sea water of a specific gravity of 1.028 measure 21.30 cubic feet to the ton.

Cohesiveness.—The amount of cohesiveness of a rock is ascertained by determining its crushing strength—that is, the weight in pounds required to crush it or to destroy its cohesion. The ultimate compressive strength of granite ranges from about 15,000 to 43,973 pounds per square inch,[c] but the usual range is from 18,000 to 34,000 pounds. Herrmann[d] gives the crushing strength of European granites as ranging from 1,100 to over 3,000 kilograms per square centimeter.

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[a] Text-book of Geology, 4th ed., p. 568.

[b] Stevenson, T., Harbours, p. 107.

[c] These extremes are from Wisconsin granites. See Buckley, Ernest B., On the building and ornamental stones of Wisconsin: Bull. Wisconsin Geol. and Nat. Hist. Survey, No. 4, pp. 361, 390.

[d] Herrmann, O., Steinbruchindustrie und Steinbruchgeologie, p. 43.

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Elasticity.—Tests made at the United States Arsenal at Watertown, Mass., to determine the compressive elasticity of specimens of granite from Arkansas, Connecticut, Maine, Minnesota, and New Hampshire, show that specimens of granite, in a gaged length of 20 inches and a diameter of 5.5 inches at the middle, when placed under a load of 5,000 pounds to the square inch, suffered compression ranging from 0.0108 to 0.0245 inch, resulting in a lateral expansion ranging from 0.005 to 0.007 inch, and giving ratios of lateral expansion to longitudinal compression ranging from 1:8 to 1:47.[a]

Flexibility.—Although granite contains a large amount of brittle material (estimated at from 30 to 60 per cent) and the interlocking of its various particles give to it great cohesion and rigidity, yet in sheets of sufficient thinness and areal extent it is flexible. Sheets half an inch thick and 4 feet long may be bent, as noted in the description of the Lawton quarry, at Norridgewock, in Bulletin No. 313, page 151. Whether flexibility in this case was conditioned upon a slight loosening of the grains by chemical and physical change is uncertain.

Hardness.—As will be seen by reference to the tests for hardness described on page 66, granites differ greatly in hardness. This difference is due not merely to differences in the percentage of quartz, but also to variations in the character of the feldspars.

Expansibility.—The expansibility of granite has been variously tested. Bartlett[b] found that a piece of granite coping 5 feet long, under the effect of a winter temperature of 0° F. and a summer temperature of 96° F., expanded 0.027792 inch, or 0.000004825 inch per inch for each degree. The ordnance department at the Watertown Arsenal[c] tested the granites referred to under the heading "Elasticity," and found that slabs of gaged lengths of 20 inches in passing from a cold-water bath at 32° F. through a hot-water bath at 212° F., and back again to cold water at 32° F., expanded from 0.0017 to 0.0059 inch, averaging 0.0040 inch.

Porosity.—Granite contains and absorbs water, which is held in microscopic spaces both within and between its constituent minerals. Ansted[d] states that granite generally contains about 0.8 per cent of water and is capable of absorbing about 0.2 per cent more. In other words, a cubic yard of granite weighing 2 tons contains in its ordinary state about 3½ gallons of water and can absorb nearly a gallon more on being placed in pure water for a short period. Buckley[e] found that the pore space or porosity in fourteen Wisconsin granites

[a] Report of the tests of metals, etc., made with the United States testing machine at Watertown Arsenal, Mass. (1895), 1896, pp. 339-348.

[b] Bartlett, Wm. C., Experiments on the expansion and contraction of building stones by variation of temperature: Am. Jour. Sci., 1st ser., vol. 22, 1832, pp. 136-140.

[c] Op. cit., p. 322.

[d] Ansted, D. T., quoted by Edward Hull in A treatise on building and ornamental stones of Great Britain and foreign countries, 1872, p. 30.

[e] Op. cit., p. 400.

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ranges from 0.17 to 0.392 per cent, and that the ratio of absorption (percentage of weight of absorbed water to the average dry weight of the sample) of the same granites ranges from 0.17 to 0.50. Merrill[a] has shown that certain Maryland granites absorb from 0.196 to 0.258 per cent of water after drying twenty-four hours at 212° F. and then being immersed for twenty-four hours.

Vitreousness.—The vitreousness of granite is due to that of its contained quartz. Under extreme changes of temperature, as in a city fire, where water is thrown on the stone, granite exfoliates badly. This exfoliation or shelling is attributable to the unequal expansion or contraction of its outer and its inner portions under sudden changes of temperature. It is also probably connected with the vitreousness of the quartz, and possibly also in a measure with the liquids contained in microscopic cavities of the quartz. The unequal expansive ratios of the different constituent minerals would result in general disintegration, not in exfoliation.

Buckley[b] subjected 2-inch cubes of five Wisconsin granites to high temperature tests and found that they were all destroyed at 1,500° F. One of them cracked at 1,000°; two others began to disintegrate at 1,200°. The most notable change was that "when struck with a hammer or scratched with a knife they emitted the sound peculiar to a burnt brick." Cutting[c] applied a fire test to granites from eighteen quarries in Maine, Maryland, Massachusetts, Minnesota, New Hampshire, Vermont, and Virginia, with the result that after saturation they all stood a temperature of 500° F. without damage, but showed the first appearance of injury at 700°–800° and were rendered worthless at 900°–1,000°. Twenty-three sandstones subjected to the same tests showed the first appearance of injury at 800°–900° and became worthless at 950°–1,200°. His general results agree with those of experience as to the relative fire endurance of granite and sandstone.[d] The behavior of granite under very high temperature is not attributable to any one physical property. The physical properties of granite are further discussed in Part II, under the heading "Tests of granite" (pp. 65–68).

CLASSIFICATION.

The varieties of granite are so numerous that for either scientific or economic purposes they need to be classified.

Scientific classification.—For scientific purposes granites may be classified according to their less essential mineral constituents—mica, hornblende, and augite. Thus a granite containing white mica

[a] Merrill, G. P., Maryland Geol. Survey, vol. 2, pp. 94, 95.

[b] Op. cit., p. 411.

[c] Cutting, Hiram A., Sixth Rept. Agric. Vermont, 1880, pp. 47–54; also, Durability of building stone: Am. Jour. Sci., 3d ser., vol. 21, 1881, p. 410.

[d] Merrill, G. P., Stones for building and decoration, p. 435.

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is termed a muscovite granite; one containing black mica, a biotite granite; one containing both, a muscovite-biotite granite. A granite containing black mica and hornblende is called a biotite-hornblende granite. Granites may also be classified according to both their mineral and their chemical composition. These two form the basis of the latest classification of igneous rocks, which is too complex to be outlined here.[a]

Economic classification.—For economic purposes granites may be classified first as to *texture*—as even grained, or porphyritic, or as coarse, medium, or fine, according to the scale given on page 14. Those of extra coarse or extra fine texture can be distinguished by the prefix *very*. This scale gives five grades of texture. Granites should also be classified as to *general color and shade*—as pinkish, reddish, lavender, or gray or warm gray (that is, a gray showing the presence of a slight reddish, reddish-purplish, or yellowish tinge), and as dark, medium, or light; and the dark and light gray may be modified by prefixing the word *very*. They may be further classified and designated by *the colors of their most conspicuous minerals*, the feldspars, quartz, and mica. A stone may thus be called a coarse, even-grained, warm-gray granite, with lavender and white feldspars, smoky quartz, and black mica; or another may be called a fine, even-grained, very light gray granite, with white feldspar, clear quartz, and both white and black mica. Lastly, they may be classified by their uses—as constructional, monumental, inscriptional, polish, or statuary granites. This scheme of classification will suffice for ordinary economic purposes. The outline of an exhaustive technical description of any granite can be constructed from the tests enumerated on pages 65–68.

GENERAL STRUCTURE.

The term "structure" embraces all the divisional planes that traverse the rock. These occur at intervals ranging from a microscopic distance to one measured by scores of feet, and either cross or, very rarely, give a course to the texture resulting from crystallization.

FLOW STRUCTURE.

Where two varieties of granite lie in contact, as at Redstone, N. H. (p. 177), the dividing line between them indicates the direction of their flow, for the same reason that the course of the flow of a stream would be shown by the demarcation between its water and that of a muddy tributary a little below their junction. In some places this direction is also indicated by streaks or sheets of mica scales parallel to the direction of the line between the granites. Such streaks, therefore,

[a] See Cross, Iddings, Pirsson, Washington, Quantitative Classification of Igneous Rocks based on Chemical and Mineral Characters, with a Systematic Nomenclature, Chicago, 1903; also Jour. Geology, vol. 10, 1902, pp. 555 et seq.

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when alone are regarded as indicating flow structure. They may be inclined at all angles or be in horizontal undulations with axes pitching 10° to 40°. In some Massachusetts and New Hampshire quarries the structure is parallel to the surface of the granite at its contact with overlying rocks, or surrounds in parallel bands the surface of large inclusions. (See pp. 62, 109, and fig. 5.) Flow structure also is conspicuous in the granite of Milford, Mass., and in some of the quarries of Milford, N. H. (See pp. 77, 158.) The very local character of such structural features indicates that they are not due to pressure which affected the entire region, but that they originated while the granite masses were still plastic. A granite that exhibits flow structure is called by some writers a flow gneiss.

RIFT AND GRAIN.

The rift in granite is a feature of considerable scientific interest and of much economic importance. It is an obscure microscopic foliation—either vertical, or very nearly so, or horizontal—along which the granite splits more easily than in any other direction. The grain is a foliation in a direction at right angles to this, along which the rock splits with a facility second only to that of the fracture along the rift. After a little experience an observer can detect the rift with the unaided eye, where it is marked.

The earliest mention of rift in geological literature appears to be that by J. F. W. Charpentier[a] in 1778, who noticed that granite millstones which were cut with their largest diameter parallel to the rift were much more readily worn than those cut at right angles to it, that is, parallel to the "hard way." He attributed this to a parallel arrangement of the mineral particles. The next reference to rift is by Pötsch[b] in 1803, who described it in the granites of Lausitz, in Saxony. In 1833 it was referred to by Enys and Fox[c] as characterizing the granites of Penrhyn, and was referred to in 1834 by De la Beche;[d] also in 1855 by Adam Sedgwick,[e] who attributed it to crystalline action at the time of consolidation. In 1860 C. F. Naumann[f] attributed it either to local differences of cohesion or to an inner strain possibly related to the direction of original consolidation. In 1864 G. vom Rath[g] described a diorite from Monte Adamello, in the Tyrol, without dominant rift, and observed that the rift course was, on the contrary, uniform in the granite of Monte Motterone

[a] Mineralogische Geographie des churSächsischen Lande, 1778. See also his Beobachtungen uber die Lagerstätte der Erze, 1779.

[b] Bemerkungen und Beobachtungen uber das Vorkommen des Granits in geschichtete Lagen, p. 140.

[c] London and Edinburgh Phil. Mag., 3d ser., vol. 2, pp. 321–327.

[d] Researches in theoretical geology, and Report on the geology of Cornwall.

[e] Trans. Geol. Soc. London, 2d ser., vol 3, pt. 3, p. 483.

[f] Lehrbuch der Geognosie, vol. 2, 2d ed., Leipzig, 1860, pp. 191–192.

[g] Beitrage zur Kenntniss der eruptiven Gesteine der Alpen: Zeitschr. d. Deutschen Geol. Gesell., vol. 16, pp. 249–260.

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(Baveno). In 1876 James D. Dana stated that "granite often has a direction of easiest fracture due to the fact that the feldspar crystals have approximately a uniform position in the rock bringing the cleavage planes into parallelism."[a] This is true in those places where the directions of flow structure and rift chance to coincide, and it may be true in some porphyritic granites that the porphyritic crystals are arranged with some reference to the rift, but that it is not the cause of rift is shown by the fact that the feldspar cleavages usually intersect the rift face at all angles. In 1879 Reyer[b] attributed rift to an original arrangement of particles by flowage. As rift in places crosses flow structure this explanation is also inadequate. In 1893 Carl C. Riiber, in a work on the granite industry of Norway,[c] described an augite syenite with inferior rift and grain, in which the cleavage planes of the individual feldspar crystals were parallel to the two cleavages, rift and grain, of the rock. Finally, in 1894, F. Zirkel,[d] after reviewing the opinions of his predecessors, tentatively suggested that rift may be the result of conditions of strain brought about by pressure from one side only, which failed to find adequate relief in jointing.

The only available recent American data on this subject are furnished by Tarr, Whittle, and Finlay.[e]

Tarr presents four figures reproduced from drawings made from enlarged views of thin sections showing the rift in Cape Ann hornblende-biotite granite. These figures and his descriptions indicate that rift consists of microscopic faults, most of which meander across feldspar and quartz alike, although some go around the quartz particles rather than through them. In the feldspars rift usually follows the cleavage. These minute faults are lined with microscopic fragments of the mineral they traverse and some of them send off short, minute diagonal fractures on either side. In examining such a structure it is important to make sure that the grinding of the section has not in any way modified the original fractures. Tarr adds that at Cape Ann the rift does not traverse the "knots" or the basic dikes that cross the granite.

Whittle gives two sketches made from polished surfaces of a well-known granite quarried by the Maine and New Hampshire Granite Company at Redstone, N. H. One of these sketches, made from a surface running at right angles to the rift, shows quartz and feldspar

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[a] Manual of Geology, 2d ed., 1876, p. 628.

[b] Reyer, Ed., Tektonik der Granit Ergüsse von Neudeck und Carlsbad, etc.: Jahrb. K.-k. geol. Reichsanstalt, vol. 29, 1879, p. 415.

[c] Norges granit industri; Norges Geol. undersogelse. Aarbog for 1893, No. 12, p. 45.

[d] Lehrbuch der Petrographie, 2d ed., vol. 2, 1894, pp. 52–53, p. 415.

[e] Tarr, R. S., The phenomena of rifting in granite: Am. Jour. Sci., 3d ser., vol. 41, 1891, pp. 267–272, figs. 1–4; also Economic Geology of the United States, 1895, p. 124. Whittle, Charles L., Rifting and grain in granite: Eng. and Min. Jour., vol. 70, 1900 p. 161, figs. 1 and 2. Finlay, G. I., The granite area of Barre, Vt.: Report of Vermont State Geologist, new ser., 1902, p. 54.

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grains traversed by a generally parallel set of lines corresponding to the rift planes. The lines are more numerous in the feldspar than in the quartz grains. The other sketch, made from another specimen, shows besides the rift lines another less pronounced set intersecting these at right angles. This second set corresponds to the grain. Whittle calls attention to the fact that notwithstanding the marked rift and grain at this quarry the stone stood a compression test of 22,370 pounds to the square inch, and was, therefore, not appreciably weakened by the microscopic fractures. A visit made by the writer in 1906 to the quarry at Redstone, N. H., has corroborated Whittle's observations. The details of the rift and grain structure observed are given on page 42.

Finlay, in describing the quartz of Barre granite, says: "The pronounced cracks which are seen to cross from one crystal to its neighbor, without interruption, are an indication of pressure phenomena in the magma after its consolidation. These cracks are notable as containing microscopic dendritic growths, which are analogous to the arborescent forms of MnO_2, and possibly identical with them."

Another peculiarity of rift is that the angle of its inclination may at some places be modified by gravity. Thus, in some localities a block will split at one angle from the top, but at another from the side; or, again, at one angle where the mass of the block is at the right and at another where it is at the left of the line of fracture. Experienced granite workmen at Concord, N. H., and Quincy, Mass., report that at some places a block that would show a horizontal rift when split from one point of the compass (say the north) acquires an inclined rift if split from the south or the east or west. The cause of this is not apparent. There are also indications that a slight alteration of the feldspars may improve the rift. Finally, as is well known to granite quarrymen, rift and grain are modified by temperature, the effect of winter cold in New England (frost?) being to intensify the rift and grain where they are weak.

Herrmann[a] states that in Saxony the rift is parallel to the horizontal sheets or joints. That is true for short distances in the New England quarries, but where the rift is horizontal and the sheets curve it crosses the sheets, and of course where the rift is vertical it crosses them throughout. Exceptionally, in one of the quarries at Quincy, Mass., a foreman reported to the writer a deflection of the rift in apparent relation to the increasing inclination of the sheets.

Rift and grain are not always pronounced. Either or both may be very feeble or may be absent.

At the Armbrust quarry, in Vinalhaven, Me., there is a horizontal rift confined to a 4-foot mass striking across the granite hillock.

[a] Herrmann, O., Steinbruchindustrie und Steinbruchgeologie, Berlin, 1899, p. 109.

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The presence of fairly good rift or grain is an important economic factor in the granite industry, for it diminishes both the amount of labor in drilling for blasts and in splitting.

That the rift is a factor in the crushing strength of granite is shown by the results of tests of Mount Waldo granite from Frankfort, blocks of which when placed on the bed—that is, with pressure applied at right angles to the rift—showed an ultimate strength to the square inch of 31,782 to 32,635 pounds (average, 32,208), but when placed on the side—that is, with pressure applied parallel to the rift—showed an ultimate strength of from 29,183 to 30,197 pounds (average, 29,690). In the first test the first crack appeared in the block at a pressure of from 120,000 to 123,300 pounds (average, 121,650) and in the second test it appeared at one of 107,400 to 112,600 pounds (average, 110,000 pounds).[a] Rift and grain in their relations to fluidal cavities are discussed on pages 42–47.

SHEETS.

The division of granite into "sheets" or "beds" by jointlike fractures which are variously curved or nearly horizontal, being generally parallel with the granite surface, attracted the attention of geologists long ago. In 1797 De Dolomieu, and shortly before that De Saussure, described granite sheet structure.[b]

In 1803 Pötsch[c] published a paper on the subject. In 1841 Edward Hitchcock described what he termed the "Pseudo-stratification of granite," near Worcester and Fitchburg, Mass., as a concentric, onion-like structure generally conforming to the rock surface.[d]

In 1860 C. F. Naumann[e] dealt with the subject in his text-book.

In 1863 F. von Adrian described the structure in Bohemia and regarded it as the result of cooling.[f]

In 1879 Reyer[g] described it from another part of Bohemia; and in 1894 Zirkel[h] also treated the subject in his petrography.

Although this is the most striking feature in every granite quarry and largely makes the granite industry possible, there is a great diversity of opinion as to its cause. Whitney[i] writes:

> The curves are arranged strictly with reference to the surface of the masses of rock, showing clearly that they must have been produced by the contraction of the material while cooling or solidifying, and also giving very strongly the impression that, in many places, we see something of the original shape of the surface as it was when the granitic mass assumed its present position.

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[a] Reilly, J. W., Ordnance Rept., tests of materials, etc. (1900), 1901, p. 1119. See also result of test of Concord granite, p. 147, this bulletin.

[b] Journal des Mines, VII, No. 43, p. 426.

[c] Op. cit.

[d] Final Report, Geology of Massachusetts, p. 683.

[e] Op. cit., p. 191.

[f] Jahrb. K.-k. geol. Reichsanstalt, vol. 13, pp. 155–182.

[g] Op. cit., p. 405.

[h] Zirkel, Petrographie, vol. 2, p. 52.

[i] Whitney, J. D., Geology of California, vol. 1, 1865, Geology, p. 372; also pp. 227, 417, and figs. 49–54.

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Shaler, a few years later,[a] attributed the sheet structure to expansion due to solar heat.

C. H. Hitchcock[b] notices in New Hampshire granite "numerous joints, the planes of which correspond very nearly with the slope of the hill," but does not undertake to explain them.

Vogt[c] states that the sheets in granites of southeastern Norway measure from 6 inches to 6 feet in thickness and dip from 8° to 33° on the sides of the mountains, toward the valleys, but that they are horizontal on top and approximately parallel to the surface. He shows that they are of preglacial origin, attributes them to the same cause that is postulated by Whitney for those in California, and regards them as parallel to the original surface of the granite masses.

Harris,[d] referring to the English granite quarries, writes: "In every quarry we visited we found that the direction of the 'beds' approximately corresponded with the outline of the hill on which it was situated." He offers no explanation of the phenomenon, however.

J. J. Crawford[e] describes the sheet structure at granite quarries in Madera and Tulare counties, California, as consisting of "concentric layers conforming in a general way to the contour of the hills," but suggests no cause for them.

Herrmann,[f] who made a special economic study of the granites of Saxony, writes:

> Upon closer inspection it appears that the granite sheets are elongated lenses overlying one another, of which the upper one, as a rule, has its bulging part lying in the depression formed by the two underlying lenses where they come together.

Branner[g] describes the exfoliation of the granitoid gneisses in Brazil, which he attributes only in part to changes of temperature. He calls attention to the fact that the linear expansion of a mass of gneiss 300 feet long at a depth of 15 feet from the surface under a surface temperature of 103° F. would amount to only 0.072 inch; and he quotes the results of Forbes, Quetelet, and others to show that the annual change of temperature can penetrate rock only to a depth of 40 feet in temperate regions and still less in the Tropics.

Merrill[h] describes Stone Mountain, in Georgia, as a boss of granite 2 miles long by 1½ miles wide and 650 feet high, which owes its form

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[a] Shaler, N. S., Notes on the concentric structure of granitic rocks: Proc. Boston Soc. Nat. Hist., vol. 12, 1869, pp 289-293.

[b] Geology of New Hampshire, vol. 2, 1877, pp. 511-512 and plate opposite p. 158, showing sheet structure at the "Flume."

[c] Vogt, J. H. L., Sheets of granite and syenite in their relation to the present surface: Geol. Föreningens i Stockholm, Förhandl., 1879, No. 56, vol. 4, No. 14; also Nogle, Bemaerkninger om Granit: Christiania videnskabsselsk. Förhandl., 1881, No. 9.

[d] Harris, George F., Granites and our granite industries, London, 1888.

[e] Twelfth Rept. State Mineralogist of California, 1894, pp. 384-387 and 3 plates.

[f] Herrmann, O., Technische Verwerthung der Lausitzer Granite: Zeitsch. für prakt. Geologie, Nov., 1895, Heft 2, p. 435.

[g] Branner, John C., Decomposition of rocks in Brazil: Bull. Geol. Soc. America, vol. 7, 1896; Exfoliation, pp. 269-277, Temperature and exfoliation, pp. 285-292.

[h] Merrill, George P., Rocks, rock-weathering, and soils, 2d edition, 1906, p. 231.

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wholly to exfoliation parallel to preexisting lines of weakness. The mass appears to be made up of imbricated sheets of granite which he regards as the result of torsional strains. The bosslike form is incidental and consequent. Intermittent expansion and contraction from changes of temperature have so affected the sheets that bound the mass at the sides that they have found relief in expansion in an upward direction. These ruptured sheets are rarely more than 10 inches thick, but are 10 or 20 feet in diameter.[a]

Herrmann[b] sums up his conclusions on the subject substantially as follows: The so-called sheets are thin near the rock surface, generally only a few centimeters thick, but become gradually thicker with increasing depth. This downward increase in the thickness of the sheets is generally more rapid where the texture of the stone is coarser. The course of the sheets is not, as Vogt claims, parallel to the original surface of the consolidating rock. It is not governed by internal strains. The attitude of the sheets corresponds to the form of the present rock surface. The sheet structure is to be looked upon as the effect of the beginning and progress of weathering from the surface inward. These weathering cracks are determined by the form of the rock surface instead of that being determined by them.

Turner[c] calls attention to the sheet structure and exfoliation of Fairview Dome, in the Yosemite.

Gilbert[d] shows that sheet structure occurs in synclinal as well as in anticlinal attitude—in other words, is parallel to hollows as well as hills—which he considers unfavorable to the theory that it is an original structure. He suggests that sheet structure may possibly be due to expansive stress consequent upon relief from compressive stress brought about by the removal of the mass into which the granite was intruded. Subordinately he notes that in the Sierras, at least, the dome structure and the parallel joint structure do not occur in the same place and that the former has resisted general erosion more successfully than the latter.

Dr. G. F. Becker, in a recent conversation with the writer, stated that he had found the granites and gneisses at the bottom of the Colorado Canyon both vertically and horizontally jointed. If these are true granites and are still in contact with the rocks into which they were intruded and show genuine sheet structure the phenomenon

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[a] For description and representations of Stone Mountain see Merrill, as above, Pl. I: Purington, Chester W., Geological and topographical features of the region about Atlanta, Ga.: Am. Geologist, vol. 14, 1894, pp. 105-108 and Pl. IV; also Watson, Thomas L., Bull. Georgia Geol. Survey No. 9-A, 1902, p. 113, and Pls. I-VIII. See also description of another granite dome—Stone Mountain, in North Carolina—by Watson and Laney, in Bull. North Carolina Geol. Survey No. 2, 1906, Pl. XXV.

[b] Herrmann, O., Steinbruchindustrie und Steinbruchgeologie, 1899, pp. 109-111.

[c] Turner, H. W., The Pleistocene geology of the south-central Sierra Nevada, with especial reference to the origin of the Yosemite Valley: Proc. California Acad. Sci., 3d ser., Geology, vol. 1, No. 9. 1900; Formation of domes, pp. 312-315, and Pl. XXXVII.

[d] Domes and dome structure of the high Sierras. Bull. Geol. Soc. Am., vol. 15, pp. 29-36, and pl. 3, 1904.

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would conclusively prove that such structure may occur independently of solar heat and load.

Mr. S. F. Emmons similarly stated that in the Mosquito (Park) Range, in Colorado, the pre-Cambrian granite and schist are cut by horizontal joints to a depth of 50 feet below their contact with the overlying Cambrian, the joints diminishing in number downward. The original load upon the granite here consisted of at least 10,000 feet of Paleozoic and between 5,000 and 6,000 feet of Cretaceous rocks. As the granite, however, was not intruded into Cambrian sediments it must have been exposed to atmospheric erosion before they were deposited. These horizontal joints may therefore have been related to solar temperature.

Mr. G. K. Gilbert has recently studied the granite domes of Georgia and attributes their sheet structure to compressive strains. He finds that the granite in these domes[a] is not naturally divided into plates, but that the outer parts of the granite—the parts nearest the surface—are in a condition of compressive strain, which results in slow exfoliation and which enables quarrymen, by means of carefully regulated blasts, to develop joints that run approximately parallel to the surface, so that the granite is detached in sheets. As these sheets are divided into blocks in the process of quarrying, the blocks expand horizontally as they are released from the general mass. In these granitic domes parting planes also develop naturally within a few inches of the surface, and the expansive force is there so great as to induce conspicuous buckling in the thin sheets thus formed. This buckling is illustrated in Pl. VII, *A*, Bulletin No. 313, from a photograph taken by Mr. Gilbert. The jar of blasting precipitates this sheeting action, so that several of the domes at which quarrying is in progress show long lines of freshly formed disrupted arches. Mr. Gilbert found that the horizontal elongation, or rather the elongation coincident approximately with the contour of the dome surface, amounted, by one measurement, to three-fourths inch in a length of 40 feet.

The effects of compressive strain on granite were observed by the writer in 1907 at a quarry at the west foot of Black Mountain, a domelike mass in West Dummerston, near Brattleboro, Vt., and are illustrated in Pl. VIII, *B*. New thin sheets have thus been formed and one of the sheet fractures opened 3½ inches.

The artificial production of sheets in granite, as practiced at Bangalore, in southern India, shows similar phenomena. It is described by H. Warth[b] in substance as follows: At the surface there is a horizontal sheet of rather weathered rock 4 feet thick; below this

[a] Letters to writer dated May 4 and June 11, 1906.

[b] The quarrying of granite in India: Nature, vol. 51, 1895, p. 272.

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lies a sheet of fresh rock 3 feet thick, but below this lies fresh rock without split. These sheets "are probably due to the variations of temperature, daily and seasonal." By means of wood fires plates 60 by 40 feet by 6 inches in thickness are detached in one piece. A line of fire 7 feet long is gradually elongated and moved over the granite. The effect of the fire is tested by hammering the granite in front of it, and then the fire is moved forward. The maximum length of the arc of fire is 25 feet. The burning lasts eight hours; the line of fire is advanced 6 feet per hour. The area passed over by line of fire is 460 square feet. The amount of wood used is 15 hundredweight. The average thickness of stone is 5 inches and its specific gravity is 2.62. These data show that 30 pounds of stone are quarried with 1 pound of wood. Some plates are taken out in inclined position. The action of fire is independent of the original surface of rock; also of the direction of lamination (the granite is gneissose) and of veins. The uniformity in the thickness of the sheets is attributed to the regulating influence of preexisting cracks.

Van Hise, in his treatise on metamorphism,[a] is inclined to attribute sheet structure to solar temperature.

Sheet structure, as exposed at the Maine quarries, is described in Bulletin 313, on pages 33–35, and is illustrated in Pls. II, *B*, III, V, VI, and IX, *A* of that bulletin. Sheet structure, as exposed at the quarries mentioned in this bulletin, is described under each quarry. Its general character is illustrated in Pls. III, *A*, and V, *A;* its relation to surface form in Pl. VII, *A*, and to overlying rocks in Pls. VI, *A*, and IX, *A*.

The observations as to sheet structure, made at over 100 granite quarries in Maine and at many of those described in this bulletin, are here summarized:

1. There is a general parallelism between the sheets and the rock surface, resulting in a wavelike joint structure and surface over large areas.

2. The sheets increase in thickness more or less gradually downward.

3. The sheets are generally lenses, though in some places their form is obscure. Their thick and thin parts alternate vertically with one another. The joints that separate these superposed lenses therefore undulate in such a way that only every other set is parallel.

4. On Crotch Island, Maine, the sheet structure extends to a depth of at least 140 feet from the surface, and at Quincy to 175 feet.

5. There are indications here and there that the granite is under compressive strain, which tends to form vertical fissures or to expand the sheets horizontally so as to fill up small artificial fissures or to extend the sheet partings horizontally. (See pp. 28, 96, 126, 191.)

[a] Mon. U. S. Geol. Survey, vol. 47, pp. 434–439.

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The observations made in Europe and in this country, taken in connection with the various inferences geologists have drawn from them, indicate that sheet or "onion" structure in granite rocks is due to the following possible causes:

1. To expansion caused by solar heat after the exposure of the granite by erosion.

2. To contraction in the cooling of the granite while it was still under its load of sedimentary beds, the sheets being therefore approximately parallel to the original contact surface of the intrusive.

3. To expansive stress or tensile strain brought about by the diminution of the compressive stress in consequence of the removal of the overlying material.

4. To concentric weathering due to original texture or mineral composition. This action would be chiefly chemical and would be aided by vertical joints and by any superficial cracks due to expansion and contraction under changes of temperature.

5. To compressive strain akin to that which has operated in the folding of sedimentary beds.

6. To the cause named under 1 at the surface, but to the cause named under 5 lower down.

These propositions will be considered in the order given:

1. Solar heat may produce a certain amount of exfoliation in thin sheets at the surface, as is proved experimentally in the fire method of granite quarrying in India (p. 25), but as it penetrates only to a depth of 40 feet and as sheet structure is known to occur on Crotch Island, Maine, at a depth of 140 feet and at Quincy, Mass., at a depth of 175 feet, it is quite inadequate to account for sheets that are 20 to 30 feet thick and 100 to 175 feet below the surface.

2. In view of the load under which granite was probably formed, as shown by the presence of liquid carbonic acid in its quartz[a] and the gradual rate at which, therefore, it probably cooled, which is also indicated by the general coarseness of its texture, it is very improbable that the temperature at its contact surface and the temperature at depths 100 or 200 feet below could have so greatly differed as to bring about such a system of joints by contraction.

3. As Gilbert states, in suggesting the theory of fracture by relief of tensile strain through the erosion of overlying masses, we have no distinct knowledge of it. It is a possible explanation.

4. Careful inspection of the rock on both sides of the sheet joints fails to show any difference in texture or mineral composition. The

[a] See also Sorby, H. C., On the microscopic structure of crystals, indicating the origin of minerals and rocks: Quart. Jour. Geol. Soc. London, vol. 14, 1858, pp. 453 et seq.; Ward, J. Clifton, On the granitic, granitoid, and associated metamorphic rocks of the Lake district: Ibid., vol. 31, 1875, pp. 568–602. Rosenbusch claims that the great variation in the relative dimensions (amount) of the liquid and the vacuoles in the cavities of granitic quartz shows conclusively that the vacuole was not due to the contraction of the liquid. Mikroskopische Physiog. der Min. und Gesteine, vol. ii (1), 4th edition, pp. 41, 42. For drawings of these cavities and vacuoles see Judd, J. W., Volcanoes, 1881, figs. 8, 9, pp. 61–66.

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sheet structure traverses both rift and flow structure, and it would be possible to procure specimens showing a sheet joint traversing a single crystal of feldspar. Whatever chemical action has taken place along the sheet joints is of secondary character. Acid waters may have gained access to the joint, but have not caused it. See matter under heading Discoloration ("Sap," etc.), page 35.

5. The condition of strain described by Merrill and Gilbert as existing in the granite domes of Georgia and by Niles and Emerson in the gneiss at Monson, Mass.,[a] and by the writer at West Dummerston, Vt. (p. 25 and Pl. VIII, *B*), and occurring to a lesser extent in some Maine quarries, shows that granite and gneiss are in places still under compressive strain. Another instance occurs at the quarry of the New England Granite Works, at Concord, page 148. The foreman at this quarry was in the habit of calling certain sheets, marked by the absence of discoloration, "strain sheets," to distinguish them from the others. At one place a northwest-southeast compressive strain had actually extended the strain sheet about 5 feet, and also caused a vertical fracture that extended over 15 feet diagonally from the north-south working face to a point on a vertical east-west channel 5 feet back of the face, closing up the channel to half its original width. Evidences of compressive strain were also noted at Quincy, page 96, and Rockport, Mass., page 126, and at Westerly, R. I., page 191, and have also been observed by the writer in some of the Barre and Woodbury, Vt., quarries. The practicability of developing sheet structure by the use of explosives and compressed air, as is done in some of the North Carolina granite quarries, shows that the rock is under a compressive strain there.[b]

All these observations bring this theory within the domain of inductive science. If sheet structure is due to compressive strain, it is due to such a strain as would produce a series of undulating fractures extending entirely across a granite mass several miles in diameter and to a depth, as far as observed, of 175 feet from the rock surface.

6. In view of the undoubted sheeting effect of expansion under solar heat within a short distance of the surface and of the fact that some of the sheets near the surface measure but a few inches in thickness, it is quite possible that very thin surface sheets have originated in this way; but in view of what was stated under heading 5 it seems probable that compressive strain is the main factor in producing massive sheets. At the surface both causes may have cooperated. The progressive thickness of the sheets downward indi-

[a] Niles, W. H., Some interesting phenomena observed in quarrying: Proc. Boston Soc. Nat. Hist., vol. 14, 1872, pp. 80-87, and vol. 16, 1874, pp. 41-43. Emerson, B. K., Geology of Old Hampshire County, Mass.: Mon. U. S. Geol. Survey, vol. 39, 1898, pp. 63-65.

[b] Watson, T. L., and Laney, F. B., The building and ornamental stones of North Carolina: Bull. North Carolina Geol. Survey No. 2, 1906, pp. 157-160.

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cates that the operation of this strain is evidently also dependent upon distance either from the present surface or from a former surface or contact.

According to this view sheet structure may be said to exert a controlling influence upon surface forms, yet it seems quite admissible that granite domes as conspicuous as Stone Mountain, in Georgia, and Fairview Dome, in California, notwithstanding all the exfoliation that has taken place on them or the erosion they may have suffered, may still retain some degree of parallelism between their present form and the original contour of the granitic intrusions of which they are parts. This may be true, also, of the granite hills of Mount Desert.

The probability being admitted that the general parallelism between the present surface and the sheet structure is the result of erosion that followed the sheeting, the question still remains, What has determined the form and location of the domes? These may possibly be referred to major arches (anticlines) in the folds of the stratified rocks which originally overlay the granite. The crustal movement that produced these folds may also have brought about the intrusion of the material that formed the domes beneath them.

Although the sheet structure and the rock surface are very generally parallel, they are not universally so.

Sheet structure in granite so much resembles the structure of folded stratified rocks that underground water circulates in practically the same way along the fracture planes of one and bedding planes of the other. The exudation of water along sheet joints on vertical rock faces is seen in many of the Maine quarries, and is also shown in Pl. V, *A*, and Pl. IX, *A*, representing Rockport and Niantic quarries.

JOINTS.

Herrmann[a] divides joints into two groups—joints formed by lateral compression, whose distances from one another are related to the coarseness of the rock texture, and joints due to expansion, some of which are parted and filled with calcite, quartz, pegmatite, or volcanic rock. That many joints are due to compressive or torsional strain, and that every such strain resolves itself into two components, resulting in two sets of joints that intersect at an angle of about 90°, each forming an angle of about 45° with the direction of the strain, are facts now generally recognized. Crosby[b] has suggested that torsional strains may have been supplemented by vibratory ones in causing joints. Becker,[c] in a recent paper, shows that four or even

[a] Herrmann, O., Steinbruchindustrie und Steinbruchgeologie, 1899, p. 103.

[b] Crosby, W. O., The origin of parallel and intersecting joints: Am. Geologist, vol. 12, 1893, pp. 368–375.

[c] Becker, George F., Sifnultaneous joints: Proc. Washington Acad. Sci., vol. 7, July, 1905, pp. 267–275, Pl. XIII.

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more than four systems of joints may be due to a single force. He also shows that subsequent strain on a region thus jointed would tend to produce motion along the previously formed joints rather than a new system of jointing. It is conceivable that if a region had been jointed and afterwards subjected to a tensile strain, some of its joints might be parted, and if they were very deep the openings might become filled with volcanic matter from below, or, if not, with matter from above, infiltrated from overlying rocks. That motion has occurred along some of the joints in the quarries is evident from the polished and striated surfaces of the joints as well as from the faulting of the sheets.

Joints are exceptionally as curved "as the side of a ship." (See Bull. 313, Pl. VI, *B*.)

Possibly related to such curved joints are what some New England quarrymen term "toe nails." These joints strike with the sheets, but extend only from one sheet surface to the next, and have a curve which sharply intersects that of the sheet structure. Such joints seem to be due to a strain different from that which produced the sheets. They were noted at Quincy, Westerly, and Milford, N. H.

The spacing of the joints varies considerably, ranging from 1 foot to 500 feet, but usually from 10 to 50 feet.

In some localities the jointing is very irregular. The granite is broken up into various polygons, which at the surface, where weathering has made inroads, resemble bowlders. Quarries opened in such places are called bowlder quarries. Another sort of irregularity in joints consists in their discontinuity or intermittence, their strike and dip for the short spaces in which they occur being uniform. Joint courses at the quarries referred to in this work are given under the quarry descriptions in Part II and where numerous are shown in diagrams.

HEADINGS.

In some places joints occur within intervals so short as to break up the rock into useless blocks. For a space of 5 to 50 feet the joints may be from 6 inches to 3 feet apart. A group of close joints is called by quarrymen a "heading," possibly because, when practicable, such a mass is left as the head or wall of the quarry. (See Bulletin 313, Pls. VIII, *A*, and IX, *B*, also this bulletin, Pl. VI, *B*.) Headings afford ample ingress for surface water, and consequently the granite within a heading is generally badly stained, if not decomposed. This will be referred to more fully under the heading "Decomposition" (p. 36).

An interesting feature of both headings and joints shown in some of the deeper quarries at Quincy, Mass. (p. 97), is their vertical discontinuity. A heading occurring at the surface may disappear

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below, or a heading may abruptly appear a hundred feet below the surface and continue downward.

Headings are not easily accounted for. They may be produced by vibratory strains that recur at intervals of time. If they are so caused, the character of the fractures in some headings indicate that the strains are very complex. (See Concord, p. 145.)

The courses of headings at each quarry are given in the descriptions of the quarries in Part II.

FAULTS.

The polished and grooved faces ("slickensides") observed on many of the joints at the quarries show that faulting has occurred along them. The discontinuity of the sheets at some of the joints, causing, where the joints are slightly inclined, what quarrymen call "toeing in," may probably be attributed to faulting. This supposition assumes, of course, that the sheet structure was formed prior to the jointing. Faulting occurs also along sheets, displacing vertical flow structure, or vertical dikes. (See Bulletin 313, Pl. VIII, *B*.) It may occur along one of two intersecting dikes, displacing the other, as at the Deep Pit on Cape Ann. (See Pl. V, *B*, of this bulletin.)

MICROSCOPIC FRACTURES.

In some quarries the granite near the surface acquires a marked foliation, which appears to be parallel to the sheet structure, and in places to the rift. This foliation is known by quarrymen as "shakes." It occurs both at the top and at the bottom of the sheet, through a maximum thickness of 6 inches. It is coextensive with the discoloration known as "sap" and occurs at many places near vertical joints. Under the microscope this structure proves to consist of minute, nearly parallel fissures, of no great continuity, which traverse the mineral particles and which in the thin section examined are especially conspicuous in the quartz and the mica. The distance between these fissures measures from a tenth to a half a millimeter, or from one two hundred and fiftieth to one-fiftieth inch. The parallelism, both to the sheets and the "sap" and its relation to the vertical joints, indicates that the structure may be due to the freezing of surface water which has found its way to the sheets through the vertical joints and has entered the rift fissures.

The writer's attention was called to a similar structure in a quarry at Milford, N. H., consisting of short, parallel fractures along the rift, from one-half inch to 2 inches apart, having no apparent connection with joints or discoloration. This is probably due to strain affecting part of the granite mass and producing miniature sheet structure.

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SUBJOINTS.

Careful inspection shows that the joint structure in granites does not everywhere consist of a simple fracture, but that it is at many places complex. Minute fractures branch off from the joint at an acute or right angle and penetrate the rock a few inches, or the rock for a few inches on either side of the joint is traversed by microscopic fissures that are roughly parallel to it. All such structural features may properly be called subjoints. (See further, p. 48, and Pl. III, *B;* also Bulletin 313, p. 41.)

Woodworth has studied analogous and related structures in various rocks and has described them as "joint fringe" and "feather fractures."[a]

ROCK VARIATIONS.

Under the term "rock variations" are grouped all those variations from typical granite that are due to injection, segregation, infiltration, inclusion, and steam cavities.

DIKES (GRANITIC).

The granitic dikes in the quarries are of three kinds: Extremely fine grained granite (aplite), very coarse grained granite (pegmatite), and fine or medium grained granite.

The courses of these dikes at each quarry are given in the diagrams or descriptions in Part II. In thickness they range from a fraction of an inch to over 20 feet, but usually from 2 inches to 2 feet.

Aplite differs from ordinary granite by the greater fineness of its texture and its scant content of mica. It is known by quarrymen as "salt horse" or "white horse."

Aplite dikes are supposed to have originated in the same deep-seated molten mass as the granite they traverse, but they represent a later stage of igneous activity. The fissures they fill were the result of various tensional strains or contractions, possibly consequent upon the cooling of the granite.

In color these dikes vary from bluish gray to light and dark reddish. The texture of some aplites is so fine that the mineral particles can not be distinguished with the unaided eye; that of others is so coarse that the feldspar and mica may be thus detected. Under the microscope the dimensions of the particles range from 0.05 to 0.75 mm., the average being about 0.16 mm. for the finer ones and 0.50 mm. for the coarser ones. Some aplites have a porphyritic texture.

Most aplites contain a slightly higher percentage of silica than granite. Five analyses of aplites from the Far West made at the laboratory of the United States Geological Survey[b] show a range of

[a] Woodworth, J. B., On the fracture system of joints, with remarks on certain great fractures: Proc. Boston Soc. Nat. Hist., vol. 27, 1896, pp. 169–173, pls. 1, 2.

[b] Bull. U. S. Geol. Survey No. 148, 1897, pp. 124, 150, 206, 219.

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silica from 71.62 to 76.03 per cent and an average of 74.08, which is near the maximum of silica for granites generally.

Pegmatite lies at the other extreme. Its mineral constituents range usually from one-half inch to 1 foot or even several feet in diameter. It is reported that the crystals in some pegmatite dikes measure from 10 to 30 feet in length by 1 to 3 feet in width. The chief minerals in pegmatite dikes are the same as in granite, but they occur in different though varying proportions. With these minerals are often associated tourmaline, garnet, beryl, etc. Chemically these dikes generally contain more silica than the granite. Dikes of pegmatite are, as a rule, more irregular in width than those of aplite. They generally range in thickness from 1 inch to 10 feet.

The origin of pegmatite has been much discussed both in Europe and in this country.[a] The coarseness of its constituent minerals indicates slow crystallization, and the irregularity of the dikes shows tensional rather than torsional strain. The banding of some pegmatite dikes and the isolated lenticular character of others indicate that the dikes were filled from heated solution, while many of them differ in no respect from dikes of igneous origin except by the coarseness of their texture. For these reasons it is thought that pegmatite dikes in granite have been formed in openings and fissures that were due, possibly, to contraction while the granite was still hot and that some of these openings were filled with matter in a state of both molten plasticity and solution under pressure, and others by heated solutions that gathered matter from the adjacent granite. Howsoever derived, this dike material crystallized very slowly.

Granite.—Finally, there are dikes that differ from all those just described, formed simply of fine or medium-grained granite. (See pp. 81, 186.)

VEINS.

Quartz veins occur rarely in the Maine granite quarries (see Bulletin 313, p. 46) and at but few of the quarries here described (see pp. 104, 105). Some of these seem to be clearly of pegmatitic origin.

DIKES (BASIC).

Dikes of dark-greenish or black, hard and dense rock (diabase, rarely basalt) are of very common occurrence in the Maine and Massachusetts quarries. The courses of some of these dikes and their relation to the joints are shown in figs. 11, 12, 14, 15, 16, 17. Some of them are represented in Pl. V, *A* and *B*, and described on pages 125, 131, 138.

[a] The principal American writings on the subject are: Williams, G. H., The general relation of the granitic rocks in the middle Atlantic Piedmont Plateau; Fifteenth Ann. Rept. U. S. Geol. Survey, 1895, pp. 675-684; Crosby, W. O., and Fuller, M. L., Origin of pegmatite: Techn. Quarterly, vol. 9, 1896, pp. 326-356; Am. Geologist, vol. 19, 1897, pp. 147-180; Van Hise, C. R., A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904, pp 720-728.

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Most of these dikes are so firmly welded to the granite that hand specimens that are one-half granite and one-half diabase are readily obtained. Thin sections of the glassy rims of dikes show that the dike sent out microscopic branches for short distances into the granite, in places surrounding some of its quartz particles. (See further on the relation of dike rims to granite, p. 50.)

The geologic age of these dikes has not been precisely determined. They are considerably more recent than the granite they traverse or the dikes of aplite and pegmatite which traverse the granite.

The diabase dikes are the result of an earth movement that either opened previously formed joints or made new ones deep enough to be injected with volcanic material. How far this may have penetrated the rocks which overlay the granite, or whether it overflowed at their surface, can not even be conjectured.

At the granite quarries, wherever this course is possible, the dikes and the headings are left to form the bounding walls of the excavations.

SEGREGATIONS (KNOTS).

Quarrymen know too well that granite is often disfigured by gray or black "knots" of circular or oval irregular curved outline, ranging in diameter from half an inch to 3 feet and exceptionally even 10 feet. These were studied by geologists long ago.[a] They are finer grained than the granite in which they occur, contain nearly 10 per cent less silica, much more black mica or hornblende (which accounts for their darkness), and a little more soda-lime feldspar, and their specific gravity is about 0.09 per cent higher.

Pl. V, *A*, of Bulletin 313 shows twelve small knots in one of the Sullivan quarries, and on pages 49 and 50 of that bulletin thin sections of knots from the Maine quarries are described. Several varieties from the Quincy quarries are described on page 95 of this bulletin and one of exceptional character from Rockport on pages 64, 125.

In none of the knots is there a definite boundary separating them from the granite, excepting such as is caused by the change in the proportionate abundance of the darker minerals. The cause of knots is not perfectly understood. They are collections (segregations) generally of the darker, heavier, iron-magnesia minerals that took place while the rock was in a plastic state.

GEODES.

Small cavities lined with crystals occur in granite. They have been found by the writer at the Jonesboro and Marshfield quarries

[a] Phillips, J. A., On concretionary patches and fragments of other rocks contained in granite: Quart. Jour. Geol. Soc. London, vol. 36, 1880, pp. 1–22, Pl. I. Merrill, G. P., On the black nodules or so-called inclusions in the Maine granite. Proc. U. S. Nat. Mus., vol. 6, 1883, pp. 137–141. Grimsley, G. P., Basic segregations: The granites of Cecil County in northeastern Maryland: Jour. Am. Soc. Nat. Hist., Apr. and July, 1894. Daly, Reginald A., Basic segregations: The geology of Ascutney Mountain, Vermont: Bull. U. S. Geol. Survey No. 209, 1903, p. 164.

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in Maine and at Redstone, N. H. Their greatest diameter was about 12 inches, and the lining crystals were quartz, more or less amethystine, and feldspar. These were usually coated with epidote, chlorite, and calcite; the calcite generally in very obtuse rhombohedra up to half an inch across. A geode at Redstone is surrounded by a band of aplite.

Such cavities are attributed to bubbles of steam or gas that were in the rock while it was in a molten state, which gave room for the growth of crystals and later became filled with epidote and calcite.

INCLUSIONS.

Not to be confounded with "knots," although some of them are equally dark and occur near them, are irregular or angular particles of various schistose rocks which the granite incorporated into itself during its intrusion. They can usually be distinguished from the knots by their different microscopic structure. In the Maine quarries they range from an inch to 40 feet in length. Part of the jagged edge of the lower part of a large schist inclusion in granite at Freeport, Me., is shown in Pl. VII, *B*, of Bulletin 313.

Inclusions in the granites of Concord and Milford, N. H., are described on pages 151, 153, 169, 176 of this bulletin.

DISCOLORATION ("SAP," ETC.).

Rusty (limonite) staining along the upper and lower parts of the sheets and also along the joints and headings is common in granite quarries, although some quarries are almost entirely free from it. The zone of discoloration along the sheets in the Maine quarries is from one-half to 12 inches, exceptionally even 18 inches, wide on each side of the sheet parting. Its width, however, decreases gradually from the surface sheets downward. In places the sap consists of two parts—an outer dark brownish zone from three-fourths to 1½ inches wide and an inner more yellowish zone from one-fourth to one-half inch wide. Generally, however, the discoloration diminishes gradually from without inward. In some quarries there seems to be a connection between the "shake" structure and the discoloration, since these are coextensive.

When the stone is intended for facing or trimming buildings the presence of sap is a serious matter as the stained edge of each block must be split off, which adds somewhat to the cost of production.

This discoloration has been supposed to be always due to the oxidation of the ferruginous minerals of the granite, biotite, hornblende, magnetite, and pyrite, but the Maine thin sections examined by the writer do not bear out this theory. (See Bulletin 313, p. 53 and fig. 2.)

These observations lead to the inference that the discoloration called "sap" is, in some Maine granites, not due chiefly to the oxida-

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tion of the ferruginous minerals of the granite by "underground water," but chiefly to the deposition of limonite by ferruginous surface water. The water descended along the vertical joints and then flowed along the sheet partings and permeated the rock above and below them. Whether the postglacial submergence of the Maine coast had anything to do with the discoloration is not clear.

Another kind of discoloration, which is even more serious in its consequences, appears on fresh faces of granite, either in the quarry or after its removal. This consists of sporadic rusty stains from half an inch to 1 inch in diameter, arising from the oxidation of minute particles of some undetermined ferruginous mineral, possibly allanite. Such stains usually, however, arise from pyrite particles or crystals.

Daly[a] describes a bluish-gray syenite, from Windsor, Vt. (feldspar, quartz, hornblende, augite, biotite), that after twenty-four hours' exposure assumes a greenish tinge, which eventually becomes more or less brownish. He has demonstrated by experiment with oxygen that this change is due to the oxidation of minute blackish granules of ferrous oxide within the feldspar, giving a yellow which, in combination with the original bluish tint of the feldspar, produces a green. The large columns of the library of Columbia University, in New York, are made of this rock.

Another kind of discoloration occurs on either side of diabase or basalt dikes, caused mainly by various alterations of the feldspars and their consequent change in shade or color. See Bulletin 313, page 91, and the examples at Rockport, Mass., and Milford, N. H., described on pages 125,163 of this bulletin. Discoloration is thus of five kinds: That due to the infiltration of ferruginous water, that due to the oxidation of the generally disseminated ferruginous minerals (biotite, hornblende, and magnetite) by nonferruginous water, that due to the oxidation of sporadic ferruginous minerals, that arising from the oxidation of ferrous oxide within the feldspars, and that due directly or indirectly to dikes and veins. The subject of granite discoloration will be found discussed further on pages 51–55.

DECOMPOSITION.

Notwithstanding the strength and durability of granite, it is liable, under certain conditions and in the course of long time, to decompose into a clayey sand. This is the result of its physical, mineralogical, and chemical constitution and properties. One of the most striking illustrations of this is the occurrence in some of the Maine quarries of "beds" of sand or decomposed granite within the fresh granite, either between the sheets away from headings or within the headings

[a] Daly, Reginald A., The geology of Ascutney Mountain, Vermont: Bull. U. S. Geol. Survey No. 209, 1903. pp. 51–53.

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and along or across the sheets. Thus at the Palmer quarry, in Vinalhaven, 20 feet below the surface in the face of the quarry, there is a bed of granite sand 18 inches thick between two sheets, which at that point dip about 10° into the hill. On the southeast side of the Longfellow quarry, near Hallowell, some of the sheets within a wide heading include granite sand beds that are about 10 inches thick. At the Shattuck Mountain quarry, near Redbeach, a 6-foot heading includes a vertical layer of granite sand 8 inches thick. Specimens taken from these various sand beds show that the disintegration begins with microscopic fractures; in some cases the enlarged rift cracks, producing the "shake" structure described on page 31, and is followed by more or less kaolinization of the feldspars. This process consists in the loss of alkali and the taking up of water, resulting in the passing of the feldspar into a white clay (kaolin).

The joint and sheet structure affords ingress to surface water, containing its usual percentage of carbonic acid, and the "rift" or "shake" structure facilitates the kaolinization of the feldspar on either side of the sheet parting by this water. As the feldspars pass into clay the rock crumbles into sand consisting of quartz, mica, and kaolin, and of feldspar in various stages of kaolinization. In some places within the range and depth of frost a large part of this work may have been done by frost alone. The sand would there be mainly the product of the "shake" structure.

In regions which have not been swept by a continental glacier any granite mass would be covered with the products of the decomposition of its own surface. In the Tropics the abundant rainfall and the organic acids from a luxuriant vegetation materially hasten the decomposition, and granitic rocks in such regions are for these reasons often covered with many feet of sand and soil.[a]

The incipient stage of weathering may be observed in any long-exposed granite ledge in the milky whiteness of the feldspars. This change usually attacks the soda-lime feldspars first. The black mica, owing to its content of iron oxide, is also liable to early decomposition. The process of weathering, as it affects the rock as a whole, involves the following chemical changes: A loss of lime, magnesia, potash, and soda; a gain of water, and a relative gain of silica, alumina, and iron oxide—that is, relative to the reduced weight of the weathered rock. The subject of weathering of granite is fully treated in the writings of Merrill, Keyes, and Watson.[b]

[a] Branner, John C., Decomposition of rocks in Brazil: Bull. Geol. Soc. America, vol. 7, 1896; Exfoliation, p. 31.

[b] Merrill, Geo. P., Disintegration of the granitic rocks of the District of Columbia: Bull. Geol. Soc. America, vol. 6, p. 321, 1895; also A treatise on rocks, rock-weathering, and soils, New York, 1897, pp. 206–214, 236, 244, 245, 257. Keyes, Charles R., The origin and relations of central Maryland granites: Fifteenth Ann. Rept. U. S. Geol. Survey, 1895, p. 725, and pls. 42–45. See also Proc. Iowa Acad. Sci., vol. 1, pt. 3, pp. 22–24, and vol. 2, pp. 27–31, Pls. II–IV, 1895. Watson, Thomas L., A preliminary report on a part of the granites and gneisses of Georgia, 1902, pp. 299, 300, 308, 329, 331, 333.

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The changes in granite after it has entered into buildings or other constructions are less marked than those in the natural rock, because the blocks are not then traversed by anything analogous to sheet and joint structure, and also because the years of historic time are few compared to those of geologic time. Much has been written on the decay of granite in monuments and buildings.[a] Such decay is mainly attributable to microscopic fissures produced by the unequal and repeated expansion and contraction of the different minerals of the granite under changes of solar temperature. In countries where the winter temperature is very low the action of frost within such fissures powerfully assists the process of disintegration. Thus the obelisk now in New York suffered more from three years' exposure to our climate than it had during over three thousand four hundred years in Egypt, although the fissures along which frost operated were started long before it reached this country. A minor factor in decay is the chemical action of water along fissures.[b]

It is supposed that these causes of decay operate more effectively in coarse granites than in fine ones. Merrill points out that a sawn or properly prepared polished surface resists weathering more effectively than a cut or hammered one, as the latter is full of minute fractures, parallel to the surface, produced by impact, which facilitate scaling.

BLACK GRANITES.

CLASSIFICATION.

The term "black granites," although sufficient for general commercial purposes, includes a variety of rocks of different character, origin, and appearance—gabbros, diorites, diabase, etc. They have, however, three mineralogical features in common—they contain comparatively little or no quartz, their feldspar belongs entirely or almost entirely to the series which contains both soda and lime, and they contain a considerable amount of one of the pyroxenes, or hornblende or biotite, and magnetite, which accounts for the general darkness of their shade or their greenish color.

ORIGIN.

The gabbros and diorites are more or less granitic in texture, as they crystallized under conditions resembling those which attended the formation of granite. But the diabase was in part erupted through narrow fissures, forming dikes or sheets, and at many places reached the surface, always crystallizing with comparative rapidity.

[a] Julien, Alexis A., The durability of building stones in New York City: Tenth Census, vol. 10, 1884; Granite, pp. 370-371. Merrill, Geo. P., Physical, chemical, and economic properties of building stones: Maryland Geol. Survey, vol. 2, 1898; Granite, pp. 92-94. Also Merrill's Stones for building and decoration, 3d ed., 1903; Weathering of granite, pp. 434, 435.

[b] See Julien, Alexis A., A study of the New York obelisk as a decayed bowlder: Annals New York Acad. Sci., vol. 8, 1893, pp. 93-166.

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Diabase, however, occurs in Vinalhaven, Me., as stated by George Otis Smith, "in large bodies which have the form of neither dikes nor sheets, being, in fact, part of the same masses as the diorites and gabbros."

MINERALOGICAL AND CHEMICAL COMPOSITION.

Gabbro consists essentially of a lime-soda feldspar and one or both of the varieties of pyroxene known as diallage and hypersthene. The former is a foliated silicate of iron and lime with about 12 per cent of magnesia; the latter is a silicate of iron with about 24 per cent of magnesia, and each of these minerals crystallizes differently. When hypersthene alone is present the rock is called a norite; when both are present it is a hypersthene gabbro. When the mineral olivine (a greenish silicate of iron with 50 per cent of magnesia) is present also the name olivine may be prefixed to the rock name. The accessory minerals in gabbros are ilmenite (a titanate of iron), magnetite, pyrite, apatite, biotite, garnet, and rarely, quartz and metallic iron. The secondary minerals—that is, those derived from the alteration of the primary ones—are hornblende, chlorite, epidote, zoisite, analcite, serpentine, a white mica, and calcite. The percentage of silica in gabbros varies a little on either side of 50. Iron oxides and lime average 9 per cent each; magnesia, 6 per cent.

Diorite consists essentially of feldspar (of the series containing lime and soda) and hornblende with biotite, or biotite alone. Quartz, augite, and potash feldspar may or may not be present. The accessory minerals are magnetite, pyrite, titanite, zircon, apatite, garnet, allanite. The secondary are epidote, chlorite, a white mica, and calcite. When quartz is present the rock is called a quartz diorite. When black mica or augite are the preponderating iron-magnesium silicates the rock becomes a mica diorite or an augite diorite. In diorites the silica ranges from about 49 to 63 per cent, but in quartz diorite it rises to about 69 per cent, which is the minimum in granite. The iron oxides range from 0.52 to 9.70 per cent, the magnesia from less than 1 to over 11 per cent, but usually from 2 to 7 per cent.

Diabase consists essentially of a feldspar of the series containing lime, or soda and lime, together with a pyroxene or augite (alumina. lime, magnesia, iron), which, however, is frequently altered to hornblende or other secondary minerals; also magnetite or ilmenite, or both. Olivine may or may not be present, and some specimens contain a little quartz. The accessory minerals are orthoclase, biotite, pyrite, hypersthene, apatite. The secondary ones are hornblende, a white mica, chlorite, epidote, serpentine, calcite. The percentage of silica in diabase ranges from about 45 to nearly 57, of iron oxides from about 9 to 14, and of magnesia from 3 to 9.

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These "black granites," as will be seen by the foregoing description, are distinguished chemically from the ordinary granites by their low percentage of silica (45 to 67 per cent), their high maxima of iron oxides (9 to 14 per cent), and of magnesia (9 to 11 per cent), and mineralogically by their dominant feldspar not being a potash feldspar, and generally also by their considerable content of the darker iron-magnesia minerals.

TEXTURE.

The general texture of the black granites corresponds in grade to that of the fine and medium granites. In the diorites the arrangement and order of crystallization of the minerals always correspond to those of the granites described on page 14. In some of the gabbros this is also true, but in others and in diabase the arrangement greatly differs. The feldspars are in needle-like crystals, between which the pyroxene has afterwards crystallized.

PHYSICAL PROPERTIES.

Aside from their great toughness, the diorites and the granitic gabbros probably differ but little in physical properties from granites of the same grade of texture. By reason both of their peculiar texture and their mineralogical composition, the diabases and gabbros with "ophitic" texture should differ considerably in physical properties from the granites. As these stones are rarely used in large buildings, owing to the difficulty of quarrying them either in blocks of sufficient size or at low enough cost, data as to their compressive strength and other useful physical properties are not available.

The specific gravity of gabbro ranges from 2.66 to about 3, that of diabase from 2.7 to 2.98, and that of diorite averages 2.95. In these rocks it thus usually exceeds that of granite.

As the black granites are used chiefly for monumental purposes, and particularly for inscriptions, their color, susceptibility to polish, and the amount of contrast between their cut or hammered and their polished surfaces are the physical properties of chief economic importance.

Doctor Merrill[a] explains the cause of these contrasts very satisfactorily:

> The impact of the hammer breaks up the granules on the immediate surface, so that the light falling upon it is reflected, instead of absorbed, and the resultant effect upon the eye is that of whiteness. The darker color of a polished surface is due merely to the fact that, through careful grinding, all these irregularities and reflecting surfaces are removed, the light penetrating the stone is absorbed, and the effect upon the eye is that of a more or less complete absence of light, or darkness. Obviously, then, the more transparent the feldspars and the greater the abundance of dark minerals, the

[a] Merrill, Geo. P., The physical, chemical, and economic properties of building stones: Maryland Geol. Survey, vol. 2, 1898, p. 64.

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greater will be the contrast between hammered and polished surfaces. This is a matter worthy of consideration in cases where it is wished, as in a monument, to have a polished die, surrounded by a margin of hammered work to give contrast.

The ordinary granites, while taking a high polish, do not afford such strong contrasts between hammered and polished surfaces as do the "black granites." In some black granites this seems clearly to be due to their larger percentage of the black minerals, but in others, as some of the quartz diorites, in which the black minerals do not exceed those in some gray granites, the cause of this marked contrast must be sought in some optical property of the soda-lime feldspar and in its relative abundance.

TEXT-BOOK REFERENCES ON GRANITE AND BLACK GRANITES.

As the matter contained in the foregoing pages may not fully provide answers to all questions that may arise in the minds of persons interested in tracing the phenomena in granite quarries to their causes, the names of a few reliable general works in English on the subjects considered are here given.

Diller, Joseph S. Educational series of rock specimens collected and distributed by the United States Geological Survey: Bull. U. S. Geol. Survey No. 150. 1898.

Granites, pp. 51, 170–180; gabbro, pp. 51, 52, 278–288; diorite, pp. 241–244; diabase, pp. 264–278; basalt, pp. 51, 52, 254–256.

Geikie, Archibald. Text-book of geology, fourth edition. London. 1903.

Granite, etc., pp. 89, 90, 203–209, 402–415, 715–809; gabbro, pp. 231, 232, 256; diorite, p. 223; diabase, p. 233; basalt, p. 234.

Harker, Alfred. Petrography for students: An introduction to the study of rocks under the microscope, second edition. Cambridge, Eng. 1897.

Granites, pp. 27–41; gabbros, pp. 67–83; diorite, pp. 54–66; basalts, pp. 188–203.

Hatch, Frederick H. Text-book of petrology, fourth edition. London. 1905.

Johannsen, Albert. A key for the determination of the rock forming minerals in thin section. New York. 1907.

Kemp, James F. A handbook of rocks for use without the microscope, third edition. New York. 1904.

The granites, pp. 33–38; gabbros, pp. 72–74; diorites, pp. 60–62; diabases, pp. 70–72.

Luquer, Lea M. Minerals in rock sections, revised edition. New York. 1905.

Merrill, Geo. P. A treatise on rocks, rock weathering, and soils. New York, second edition. 1906.

Igneous rocks, pp. 52–60; granites, pp. 61–64; diorites, pp. 76–77; diabases, pp. 82, 85; basalts, pp. 86, 87; weathering, pp. 150–273.

SPECIAL FEATURES.

The following thirteen sections contain such interesting illustrations, either of subjects already touched upon in the general discussion of granite (pp. 18–38) or of closely related ones, as were found in visiting the quarries for the preparation of this bulletin.

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RIFT AND GRAIN RELATED TO FLUIDAL CAVITIES.

Rift and grain structure was described on pages 19–22, where reference is made to Mr. Whittle's paper on this structure as shown at Redstone, N. H.[a]

During the writer's visit to Redstone a specimen of the pink granite was obtained, with a face 4¼ by 4 inches cut and polished parallel to the "hard way," that is, at right angles to both rift and grain; also a specimen of the green granite from the adjoining western quarry, 5 by 4 inches, cut and polished in the same way. Material for a thin section of the pink was also obtained and a section 1½ by 1 inch in area was cut at right angles to both rift and grain directions. The direction of the rift at the quarries was found to be horizontal, crossing the sheets which curve in anticlinal attitude across the axis of the hill with a dip of 15° both to the east and west, while the grain is vertical with an east to west course, and corresponds with the most prominent set of joints.

A careful examination of these specimens shows rift cracks in both the feldspar and quartz of the pink granite, though they are more conspicuous in the quartz, partly because of the darkness of its shade. Grain cracks are less abundant. The green granite shows both rift and grain cracks, if anything, more abundant, though not as easily seen as in the quartz of the pink granite. The large thin section shows 12 prominent rift cracks in the quartz areas in a space of 1.2 inches measured along the grain, that is, with an average distance apart of one-tenth inch. The grain cracks are far less frequent and less continuous. That these rift and grain cracks were not caused by hammering or by cutting the section is shown by the fact that some of them are filled with secondary fibrous mica. The quartz areas also show two intersecting sets of lines, really sheets or planes of gas or liquid inclusions, the latter with vacuoles. Many of these cavities are very irregular in outline, some having several ramifications. They all range in diameter from less than 0.00285 to 0.063 millimeter. The strike of these two sets of sheets corresponds respectively to that of the rift and grain. Some of the rift or grain cracks appear to have followed the sheets of cavities, for they coincide with them. Portions of this section are shown in fig. 1.

In reexamining the thin section of granite from near Pleasant Beach, in Maine, represented in fig. 1, p. 28, of Bulletin 313, sheets of cavities were found in it, some parallel to the rift cracks and some coinciding with them, but they are not so conspicuous or continuous as those in the granite from Redstone, N. H., and thus at first escaped the writer's notice. Emerson[b] in describing the granite of Becket, Mass..

[a] Whittle, C. L., Rifting and grain in granite: Eng. and Min. Jour., vol. 70, 1900, p. 161, figs. 1 and 2

[b] Emerson, B. K., The geology of eastern Berkshire County, Mass.: Bull. U. S. Geol. Survey No. 159, 1899, p. 73.

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uses these words: "The quartz grains were full of *sheets of cavities*, with large moving bubbles." Washington[a] refers to streaks of inclusions in the greenish granite of Bay View on Cape Ann: "Gas and liquid inclusions, the latter carrying a movable bubble, are quite abundant though small and occur in *streaks*."

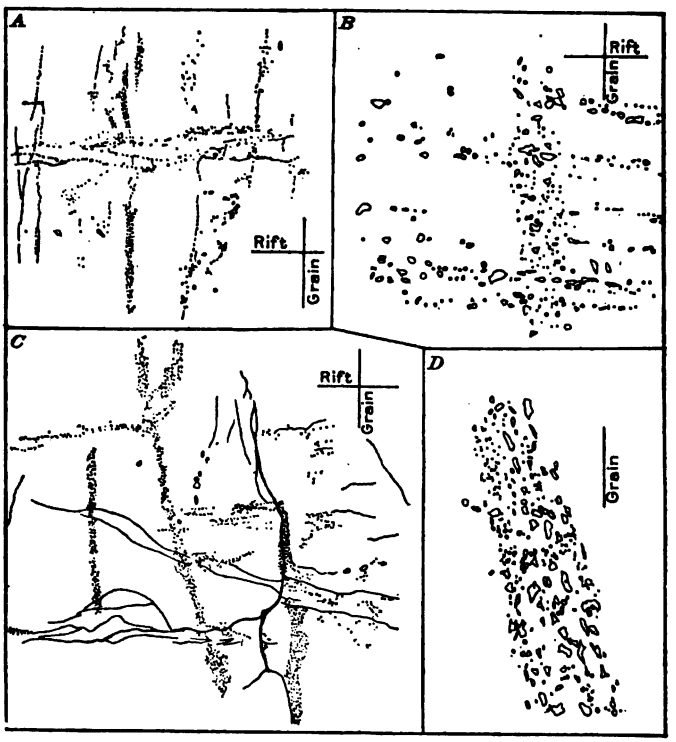

FIG. 1.—Camera lucida drawings of quartz areas in an enlarged thin section of biotite granite from Redstone, N. H., cut parallel to the "hard way." *A*, enlarged 62½ diameters, shows sheets of cavities and incipient cracks in both rift and grain directions. *B*, from a different quartz area, enlarged 175 diameters, shows the variation in the size of the cavities and their arrangement in both rift and grain directions. *C*, from still another quartz area, enlarged 23½ diameters, shows conspicuous rift and grain cracks, filled with fibrous white mica, coinciding here and there with the sheets of cavities, also two parallel exceptional fractures crossing the rift and grain directions diagonally. *D* shows part of one of the grain sheets of cavities of *C*, enlarged 175 diameters in order to show the shapes of the cavities. As most of these sheets of cavities in the section appear to undulate in the direction of the line of vision when placed under the microscope the outlines of all the cavities become visible only by altering the focus.

At the Redstone quarry at Westerly, R. I., the quartz has cavities in sheets with rift cracks parallel to them. In a veinlet of quartz and feldspar at the Calder & Carnie quarry at the same place (p. 203) the quartz particles are crowded with cavities in sheets parallel to the side of the vein and also in line with streaks of kaolinization in the feldspars. A smoky quartz vein (averaging 0.35 inch thick) of pegma-

[a] Washington, H. S., The petrographical province of Essex County, Mass., I: Jour. Geol., vol. 6 (8) Nov.–Dec. 1898, p. 790.

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titic origin, observed by the writer in 1907 in the A. Milne quarry at Barre, Vt., shows many roughly parallel diagonal fractures. In thin section it has a largely feldspathic border, 0.2 inch thick, which is partly micacized, and inside of it the quartz is in places granulated. Discontinuous sheets of cavities with vacuoles extend both in the direction of the vein and at right angles to it, and some cracks with granular quartz zigzag along these directions. In places the cavities are abundant but without apparent arrangement.

At the Milford Granite Company's quarry, Milford, N. H. (p. 173), the quartz of a quartz-augite diorite gneiss overlying the granite has cavities arranged in sheets intersecting one another. Sheets of cavities intersecting one another at right angles and with rift and grain cracks parallel to them were also observed in granite sections from the Becket, Mass., quarry (p. 141); and in several other granites described in this bulletin the cavities are arranged in rectangular sheets. This has also been found to be true in many sections of Vermont granites quite recently studied. One of these from Cobble Hill near Barre shows quartz with sheets of cavities with conspicuous rift cracks parallel to or coinciding with them. Some of the rift cracks polarize brightly and extend into the feldspars where they are clearly filled with fibrous muscovite. But in other sections, cut without reference to rift or grain directions, the sheets of cavities intersect at all angles or the cavities have no apparent arrangement. Many such irregularities thus result simply from the haphazard direction of the section. For this reason probably Rosenbusch refers to their occurrence in apparently irregular groups or courses only.

In the thin section of Redstone, N. H., granite, described on page 42, some of the sheets of cavities pass uninterruptedly, and without deflection from one quartz particle to another and the rest do not appear to terminate abruptly at the edge of the particle. The passage of sheets of cavities from particle to particle without interruption or deflection can be observed also in a section (109, specimen 36, b) from the adjoining green granite of Redstone, also in one (150, specimen 38, a) from the White Mountain quarry near North Conway. This is also the case in several sections of Quincy granite (234, specimen 79, f, from the Hardwick quarry, and 206, specimen 85, a, from the Mount Pleasant quarry, Milton) and in some (221, 228, specimen 91, f) from the Becket (Chester), Mass., quarry. There is also in all these sections a general parallelism in the sheets, which lie either in the rift or the grain directions or between these and the rift or grain cracks, but some sections also have sheets of cavities diagonal to those directions. Even sections cut parallel to rift or grain or at right angles to both usually show cavities, more or less abundant, which are without any apparent arrangement.

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These facts point to the probability of an intimate relation between the arrangement of the inclusions and the rift and grain structure. If the cavities, containing water or liquid carbonic acid, or either of these in a gaseous form, in the quartz of granite, are correctly regarded as having originated at the time of the crystallization of the material of the granite, then the rift and grain structure would seem to be either original also or, if secondary, to have had its directions generally determined by those of the sheets of inclusions.

No such rows of fluidal cavities which Rosenbusch[a] describes as connected by fine cylindrical canals and as occurring especially in granites containing quartz with crush borders, have been detected in the New England granites studied by the writer. Rosenbusch regards these as possibly of secondary origin or else caused by mountain pressure.

Van Hise[b] points out that in a certain quartzite of the Black Hills rows of minute gas- or liquid-filled inclusions running in parallel lines across the entire section, transverse to the longer axes of the quartz grains, with rows of black ferrite and secondary quartz similarly oriented, are of secondary origin. He regards them as probably due to the fracture of the grains by mechanical action and the introduction of liquid along the cracks with the later deposition of secondary quartz, which has retained the liquid as inclusions.

Some vitreous Cambrian quartzite collected by the writer near Fort Ann, Washington County, N. Y., Mettawee quadrangle, in 1899, shows in thin section enlargement of the original quartz grains by secondary interstitial quartz and also sheets of liquid inclusions intersecting one another at various angles within the quartz grains. As these sheets of cavities stop abruptly at the edge of the original quartz grains, and the courses of the sheets in different grains are not parallel but quite discordant with one another it is evident that these liquid inclusions antedate the metamorphism which produced the quartzite.[c] A thin section of a calcareous sandstone from the same vicinity shows similar sheets of cavities in its quartz grains, but their directions are such that they can have had no relation whatever to the bedding planes of the sandstone or to any secondary fractures in it, but their origin must date back to the granite or gneiss from which they came.

The inference to be drawn from the Black Hill and Fort Ann quartzites is that lines or sheets of fluidal cavities within the quartz grains of a quartzite may be secondary or primary—that is, they may have originated in the process of the formation of the quartzite or they may

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a Mikroskopische Physiographie, 4th edition, 1907, vol. 2 (1), pp. 41–42.

b Van Hise, C. R., Pre-Cambrian of the Black Hills: Bull. Geol. Soc. America, vol. 1, 1890, pp. 216–218 and fig. 4; also A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, p. 620.

c See also Merrill, G. P., Fluidal cavities in quartz grains of sandstones: Science, vol. 1, 1883, p. 221. He calls attention to the same Fort Ann sandstone or quartzite and to the rapid movement of the vacuoles within the fluidal cavities.

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have been associated with that of the parent granite or gneiss itself. The thin sections themselves will indicate in most cases the mode of origin.

Still another mode of origin of fluidal cavities is illustrated in a thin section of an inclusion of plicated fine-grained biotite gneiss (quartz, microcline, biotite, muscovite, rarely allanite) in a granite (quartz monzonite) at the Morrison quarry, on Blue Mountain, in South Ryegate, Vt., visited by the writer in 1907. This section shows parallel sheets of cavities with vacuoles, passing from one quartz grain to another, without interruption or deflection, in a direction at right angles to the foliation of the gneiss. Had these cavities been formed at the time of the intrusion of the original granite from which the gneiss was formed the sheets would hardly have preserved their parallelism under the distortion of the quartz grains. Sections across the contact of schistose inclusions with their inclosing granite from other localities in Vermont show sheets of cavities in the quartz of the granite stopping abruptly at the quartz particles of the inclusion. A thin section across the contact of granite and its original schist capping at the Marr & Gordon quarry in Barre, Vt., shows many sheets of cavities with vacuoles crossing the quartz particles at distances of from 0.094 to 0.3 mm. and roughly parallel to the contact plane of the two rocks. A few shorter sheets of cavities also cross the first set at right angles and presumably in the grain direction. Although the two rocks are firmly welded together, the sheets of cavities do not extend into the quartz particles of the schist. The presumption, therefore, is that the cavities in this Ryegate specimen originated during the last stages of the formation of the gneiss and under conditions of pressure, moisture, and heat quite as great as those accompanying the granite intrusion. The sheets of cavities observed in the gneiss capping the granite at Milford, N. H. (p. 173), and in the diorite schist capping the granite at Becket, Mass. (p. 143), probably originated in the same way as those in the Ryegate inclusion.

That these fluidal cavities in the quartz of granite are not the only factor in the origin of rift and grain structure is evident from the parallelism which exists between the arrangement of the mica scales and the rift of many granites. (See p. 146.) The detection of this arrangement of the mica is the principal means of determining the course of the rift before actual experiment. Similarly the course of the hardway in a quarried block is ascertained by the greater roughness of the particles to the touch on the hardway side than on either of the others.

A remark by Buckley[a] as to the rift in certain Wisconsin porphyritic rhyolites covers several possibilities as to the mode of origin of that structure in granite. "The rift may be the result of flowage

[a] Buckley, E. R., On the building and ornamental stones of Wisconsin: Bull. Wisconsin Geol. and Nat. Hist. Survey, No. 4, 1898, p. 446.

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planes developed before the rock was completely solidified, it may have been occasioned by alterations since the formation of the rock, or it may be the result of both."

The observations at Redstone, N. H., indicate that the arrangement of fluidal and gaseous cavities took place in rectangular directions during consolidation, and probably governed the courses of rift and grain produced by strains after consolidation; and any parallelism between the mica scales in the rift direction must be regarded as having originated at the same time as the arrangement of the fluidal cavities, and to have been governed by the same general cause.

That any alignment of the mica scales in the direction of the sheets of fluidal cavities and the rift cracks is not necessarily identical with their arrangement or that of the fedlspar by flow structure is shown by the following observations in New England granite quarries: At Mount Waldo, Frankfort, Me., flow structure strikes N. 20° W., rift is horizontal and grain vertical with N. 85° W. course. At the Tayntor quarry, Hallowell, Me., flow strikes N. 35° W., rift is horizontal and grain vertical with N. 70° W. course. At North Jay, Me., flow is horizontal in undulations 20 feet wide and rift is horizontal without grain. At Dodlin Hill, Norridgewock, Me., rift is horizontal, flow and grain are both vertical with N. 60° E. course. The Norite at the Hall quarry, near Baileyville, Me., has horizontal sheet, flow, and rift structure.[a]

At Milford, N. H. (p. 158), flow varies greatly, N., N. 15°, 20°, 50°, 70° E., and N. 75°–80° W., rift is horizontal or nearly so, and grain about vertical with N. 60°–90° W. and 80° E. course. At the Klondike quarry, near Niantic, R. I., flow is N. 10°–20° W., dipping west, intersecting a feeble horizontal rift. At Milford, Mass., there is a wide range in both strike and dip of flow, but rift is everywhere reported as horizontal and grain as vertical with N. 40°–90° E. course. In places flow and rift are parallel (p. 77).

Incidentally, attention may here be directed to a fact familiar to all geologists engaged in the microscopic examination of granites; that is, the movement of the bubbles (vacuoles) within the fluidal cavities of the quartz particles. Whether due to the effect of light or to other causes, visible motions within a rock of such density and antiquity as granite is very suggestive. These motions were found to be as perceptible within the quartz grains of the Fort Ann quartzite (noted also by Merrill, see p. 45) as in the quartz particles of the Redstone, N. H., granite. The writer has also observed them in the quartz of segregation veins in Cambrian slate from Vermont, in which the fluidal cavities obviously originated at the time of the origin of the vein.

[a] See for all these facts Bull. 313, pp. 82, 121, 151, 155, 162.

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SOME SUBJOINTS DUE TO STRAINED VEINS.

On page 32 the term subjoints was applied to certain minor joints which either branch off at various angles from main joints or are parallel and close to them. It is here extended to include also series of minor parallel joints traversing quartz veins.

Such jointed veins occur in several quarries at Quincy on the North Commons. They are made conspicuous by a zone of light discoloration in the granite on either side of the vein. At the Field & Wild quarry (see p. 105) these veins recur at intervals of 2 to 25 feet, with a north and northwest strike and a southwest dip. They are crossed every inch or two by subjoints about 1 foot long, which strike about N. 15° W. and dip east like the chief joints of that quarry. At the Galvin quarry (see p. 104) similar quartz veins, striking N. 25° W. and dipping south-southwest, are crossed by vertical subjoints an inch apart and a foot long, with a northerly strike like that of the major joints. These relations are shown in Pl. III, *B*. Workmen report that the granite near such veins is harder than elsewhere.

These subjoints may be accounted for by the greater rigidity and vitreousness of the veins and the adjacent granite, thus causing them to fracture more readily than the surrounding rock under the joint-forming movements. Although parallel to the major joints such subjoints may have been formed at a different time.

PEGMATITE DIKES IN GROUPS.

The granite of Milford, N. H., is crossed by the usual pegmatite dikes, but at several quarries instead of being single or ramifying they occur in parallel sets of three to twelve and have sinuous courses. This grouping is exceptional in the 284 granite quarries thus far visited by the writer. At the old Field quarry, near the village, the individual dikes measure from one-fourth of an inch to 1 inch in width and number up to ten in a set, and the sets recur at intervals of 15 to 20 feet. At the Hayden quarry, a mile south, such dikes, from one-fourth to 1 inch wide and up to twelve in a group, recur at intervals of 20 to 30 feet. At the Young quarry, midway between these localities, the sets consist of three to eight dikes up to 3 inches thick and recur at intervals of 20 feet. The dikes here meander and unite in the most intricate manner, occupying bands of granite 5 to 10 feet thick, which in quarrying have to be discarded. Pl. VI, *B*, shows four sets of these dikes. Somewhat similar dikes were noted by the writer in a small quarry 3 miles northeast of Lewiston, Me., where a fine-grained biotite gneiss is traversed in a space of 30 feet by 27 pegmatite dikes ranging from 1 inch to 2 feet in thickness and all dipping 80°. The pegmatite of Milford, N. H., consists of oligoclase, smoky quartz, microcline, biotite, and accessory magnetite, allanite, and zircon.

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It is difficult to explain the grouping and spacing of these dikes without supposing some periodicity in the application of the tension which made openings for them. The sinuosity of the courses of such dikes has been regarded as evidence that the openings were the result of tension rather than of compressive or other strain. (See Bulletin 313, p. 44.)

CYLINDRICAL AND OTHER IRREGULAR DIKES.

At the Ballou quarry, in Quincy (see map, Pl. II), the attention of geologists has been often drawn to a vertical cylindrical pegmatite dike about 2 feet in diameter, a horizontal section of which has for many years been exposed at the gradually deepening bottom of the quarry, which has now reached a depth of 150 feet. A block containing an entire cross section of this dike was shown to the writer by Mr. F. Wesley Fuller, of the Quincy Granite Company, at West Quincy. The general color of the dike is a light greenish gray, much lighter than the surrounding granite. Prof. Charles Palache, of Harvard University, who had been studying this dike before the writer's visit, gives the results of his observations in these words:[a]

I determined the presence in the pegmatite of ægirine and riebeckite, the latter probably the original mineral and the other formed from it. With them is fluorite, sphalerite (zinc sulphide), and galena (lead sulphide) in minute amounts, molybdenite more abundantly, danalite doubtful. The pegmatite is in no proper sense a dike as I saw it; it seems to occupy a pipe-like branching cavity with a rude radial arrangement of its constituents inward from wall to cavity. It merges outwardly insensibly into the riebeckite granite of the region. My interest in the occurrence was aroused by the unusual size of the rare forms of amphibole and pyroxene found in it.

The writer's observations follow: The section of the cylindrical mass at the Quincy Granite Company's yard has an outer rim with abundant blue-black riebeckite crystals slightly larger than those of the surrounding granite. Within this is an intermediate zone (specimen D. XXIX, 80, b) of light greenish gray feldspar and slightly milky quartz (particles up to four-fifths inch in diameter), containing bright grass-green crystals of ægirite in sizes up to 1 by one-half inch, with some purple fluorite and rusty metallic spots. The center consists mainly of quartz, with coarse feldspar outside of it. Under the microscope the feldspars prove to be orthoclase with a finely intergrown plagioclase, also particles of albite and probably oligoclase-albite. Both feldspars have the minute crystals of riebeckite and particles of epidote typical of Quincy granite. The quartz has many fluidal cavities. There are slender epidote crystals in feldspar and quartz. The riebeckite is intergrown with ægirite, and magnetite is somewhat plentiful. The feldspars are somewhat kaolinized and there is some hematite and limonite stain. The brown-

[a] From a personal letter to the writer, dated May 8, 1907, published here with the consent of Professor Palache.

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ish metallic areas of the middle zone consist of magnetite, titanite, epidote, zircon in double pyramids, allanite, fluorite, ægirite, and quartz.

This cylindrical dike is thus a riebeckite-ægirite granite; that is, a granite containing varieties of hornblende and augite rich in soda and ferric oxide, but poor in alumina, magnesia, and lime, and thus resembles the surrounding granite, but its particles are much coarser and radially arranged; some of its accessory minerals are exceptional and the others, as well as its secondary minerals, are more abundant. The accessory minerals noted either by Professor Palache or by the writer include sphalerite, galenite, molybdenite, magnetite, fluorite, allanite, titanite, and zircon. The secondary minerals are kaolin, epidote, hematite, and limonite. Both ægirite and riebeckite are regarded as primary. (See p. 97.) Mr. Fuller stated that the mass as then exposed seemed to ramify downward.

Another dike of unusual form, composed of fine-grained black hornblende diabase, is exposed at the bottom of the Rockport Granite Company's "Deep Pit," near Bay View, on Cape Ann, 195 feet below the surface, as shown in Pl. V, *B*, and in more detail in fig. 2. It dips to the north. Its original upper surface, 30 feet above its present surface, is reported as not over 8 feet in diameter. As shown in Pl. V, the quarry is traversed by two intersecting basic dikes. The one nearest to this mass, 10 feet west of it, is not a hornblende diabase (ophitic texture with hornblende and biotite), but a lamprophyre without biotite (porphyritic texture with augite). The large dike on the east side, which from its dip must traverse the granite about 80 feet east of the mass in question, proves to be also a hornblende diabase. The connection, therefore, of the central mass will, if excavations proceed deep enough, very probably be found to be with the dike on the east, not with that on the west.

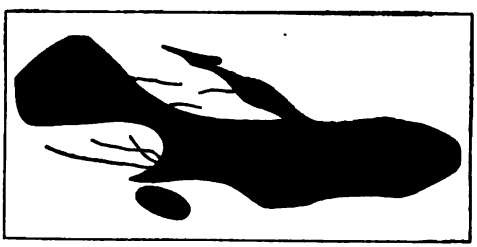

FIG. 2.—Diagram sketch of horizontal cross section of injection of hornblende diabase at Deep Pit granite quarry, near Bay View, on Cape Ann, Massachusetts. Length, north to south, 25 feet, and east to west 8 feet. The fine ramifications are up to 3 feet by 1 inch in size.

Thin sections of the fine-grained rim of one of the dikelets protruding from this mass and of the granite next to it bring out interesting facts. The rim sends out branches, from an eighth to a fourth of a millimeter long, into the granite. In places both rocks are dovetailed into one another. The rim consists of minute roundish particles of hornblende and incipient crystals of feldspar and fine particles of magnetite. There are crowds of apatite crystals along the contact and a little secondary calcite. In one place the hornblende and mag-

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netite of the dike are thickly disseminated in the granite; in another both rocks are merged into one containing the minerals of both.

This diabase mass appears to have been injected at the time of the intrusion of the other diabase dikes of the cape and to owe its shape to an irregular east-west fissure with a northern inclination. That the intrusion probably took place under considerable pressure and heat is shown by the commingling of the minerals of both rocks along their contact.

MUSCOVITE VEINS ("SAND SEAMS").

At some of the Concord, N. H., quarries the muscovite-biotite granite is traversed here and there by what quarrymen term "sand streaks" or "sand seams." These are veins of white mica from one-tenth to two-fifths inch wide with a border of quartz and feldspar about another tenth inch on each side. The mica plates measure up to 0.07 inch in diameter. Some of these veins, however, consist almost entirely of mica plates without any regular arrangement, attain a thickness of 1½ inches, and have mica plates up to 0.2 inch.

Veins of kindred but not identical character were observed at Milford, N. H. At the disused Field quarry muscovite veins, half an inch wide, with a central parting, recur at intervals of 15 to 20 feet. They strike like the pegmatite dikes referred to on page 48, and are discontinuous, not exceeding 6 feet at a stretch and being in places but a few inches. At the neighboring quarries of the Milford Granite Company there is a heading striking N. 30° E., the joints of which inclose segregation veins of muscovite and quartz, the quartz in the center. These are from 0.1 to 0.5 inch wide and the granite is discolored up to half an inch on each side. This is due to the oxidation of ferruginous matter within the soda-lime feldspars, which turns them bright reddish. The biotite is also chloritized.

It will be noticed that these Concord and Milford, N. H., veins differ in that the former usually have muscovite in the center, but in the latter quartz occupies that position. Both kinds of veins may be attributed to the percolation of mineral solutions along fissures. In either case the outer mineral was deposited first. The proximity and parallelism of many of these veins to pegmatite dikes suggest that although deposited from solutions they were probably intimately related to the pegmatite dikes and formed at the same time. In that case the heading referred to at Milford antedates the sheet structure.

FELDSPARS.

COLORS.

Although the shade of a granite is largely determined by that of its quartz particles and the relative abundance and size of its black mica scales, its color is almost always determined by that of its feldspars.

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The colors of feldspars in commercial granite are so varied as to be an object of interest not only to the geologist but to the quarryman and the architect. Even the small number of granites considered in this bulletin have feldspars of eight colors—bluish, greenish, olive-green, pea-green, cream color, pink, reddish, and greenish brown. Some are colorless and transparent, others are dark or light gray, while the colored ones may be either transparent, translucent, or opaque. The relative opacity is mainly determined by degree of kaolinization and micacization.

In some cases the origin of the color is not easily determinable. Thus the feldspar of Concord granite is translucent, with a slight bluish tinge, but the sections show no mineral which would produce such a tinge. In other cases, however, the results of microscopic examination are more satisfactory. Thus one of the Rockport granites (p. 132) owes its greenish tinge to chlorite scales and limonite stain. The Milford, Mass., granites (p. 75) have a delicate pink orthoclase and a yellow-greenish plagioclase. The greenish tint is due to innumerable minute crystals of epidote and a few scales of chlorite. The smallest of these epidote crystals measure about 0.001 millimeter. The orthoclase is much kaolinized and the cause of the pinkish tinge is not apparent but is supposed to be due to the presence of infinitesimal particles of reddish hematite (Fe_2O_3).

The reddish biotite granite of the Redstone quarry at Westerly, R. I. (p. 200), contains a pinkish potash feldspar and a cream-colored plagioclase, both translucent and more or less micacized. They are both stained reddish here and there by hematite (Fe_2O_3) proceeding from the oxidation of magnetite particles (Fe_3O_4). This shows how the reddish color may be brought about. A similar reddening of the feldspar along the joint faces at Redstone, N. H., is due to hematite plainly proceeding from magnetite particles (p. 181).

The olive-green granite of Rockport (p. 135) contains a grayish olive-green orthoclase which appears crowded with opaque particles, presumably kaolin, the largest of which range from 0.0028 to 0.014 millimeter. There is yellow limonitic ($Fe_4O_9H_6$) staining both along the rift cracks and about the opaque particles, some of which may be ferrous iron (FeO) instead of kaolin. This limonite stain, in connection with an original bluish tinge unaccounted for, produces the olive green. This granite contains also biotite and allanite. The similar olive-green granite from Redstone, N. H. (p. 182), owes its green tinge more to the color of the quartz than to that of the feldspar. The feldspar is a medium bluish gray with an occasional yellow-stained cleavage or rift crack. The limonite stain here clearly proceeds from the alteration of somewhat abundant particles and crystals of allanite,[a] as shown in fig. 3, and also from particles of hornblende.

[a] See glossary (p. 217), also Iddings and Cross, On the widespread occurrence of allanite as an accessory constituent of many rocks: Am. Jour. Sci. (3) vol. 30, 1885, pp. 108-111.

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The bluish and greenish tints of the medium to dark gray feldspar of Quincy granite (p. 92) are due to finely disseminated crystals of bluish riebeckite, measuring from about 0.001 to 0.1 millimeter in length by about 0.001 wide, and to innumerable still more minute particles of grass-green epidote.

This bluish-greenish gray feldspar of Quincy granite assumes very different colors as the result of various alterations. In places it becomes cream colored, in others a delicate pea-green or pink, or dark greenish-brownish gray, in others a light olive gray, and in others it becomes spotted with a deep red. The mode of these occurrences, the appearance of the changed feldspars in thin section, and the probable causes of the changes are as follows:

At the Galvin quarry (Pl. III, *B*, and p. 104) the granite on either side of the quartz veins, which contain a little ilmenite and carbonate, is changed for 4 inches from its usual bluish gray to cream color. At the Field & Wild quarry (p. 104) these veins are bordered by 3-inch zones of greenish, pinkish, or light grayish discoloration. The cream and light gray seem to be due not so much to the kaolinization of the feldspars and to limonite stain from the ilmenite of the vein as to a diminution of certain minute black particles which abound in the unaltered feldspar. The pinkish and greenish colors are due to hematite and epidote. The reduction of the black particles and any kaolinization of the feldspars along these veins must be attributed to carbonic-acid waters, and these must either have come from below with the silica of the vein or from above by infiltration along the vein courses.[a]

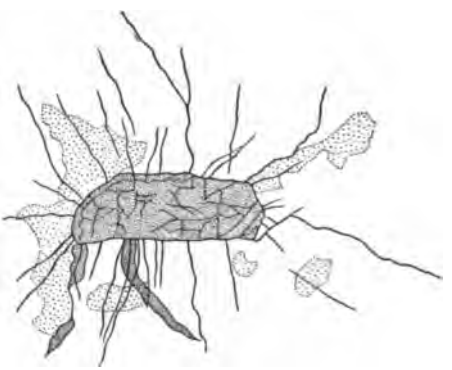

FIG. 3.—Part of a thin section of green biotite-hornblende granite from Redstone, N. H., enlarged 31½ diameters, showing a crystal of allanite with radiating cracks, which are filled with yellowish limonite stain, also bands of such stain apart from these cracks. The dotted areas are quartz, the rest feldspar. Such crystals in part account for the color of the rock.

At the Cashman quarry in West Quincy (p. 113) the granite at both the north and the south ends, to a depth of over 70 feet from the rock surface, has delicate pea-green feldspars, but normal gray granite occupies the center of the quarry. Similar pea-green feldspar occurs on the south side of the Lepage quarry (p. 112) in West Quincy to a depth of 30 to 40 feet, and at the Djerf & Winquist quarry on the North Commons (p. 101) to a depth of 125 feet from the rock surface. This pea-green tint seems to be due mainly to a large addition of mi-

[a] Van Hise, C. R., Treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904, pp. 720–728.

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nute particles and crystals of light-green epidote, and secondarily to the absence or removal of the minute riebeckite crystals. There is also here and there a secondary light yellowish brown hornblende in minute prismatic crystals. The epidotization of the feldspars in a superficial zone from 30 to 125 feet thick is intelligible, but some structural feature seems necessary to account for the separation of two vertical belts of light-green granite by a normal gray one at the Cashman quarry. As epidote is a hydrous silicate of iron, alumina, and lime, and as potash feldspar is a silicate of alumina and potash, the alteration of the latter into the former involves access of calcium and iron. Some of this calcium may have been supplied by the soda-lime feldspar intergrown with the other, or both calcium carbonate and iron may have been brought into the rock.[a]

As all the orthoclase of Quincy granite contains a little epidote the process of epidotization must in a measure have affected the entire granite mass, at least as far as 225 feet, the greatest depth reached. But in these light-green granites the process was carried much farther.

A pink granite occupies one-half of the Savo quarry (p. 114) in West Quincy, to a depth of 30 feet, and the pea-green granite the other half. The feldspars of the pink stone have been kaolinized and made pink. The larger riebeckite and ægirite particles have passed into masses (pseudomorphs) of quartz, magnetite, and carbonate, with some epidote and chlorite. Magnetite crystals are conspicuous in them. The minute crystals of riebeckite have disappeared. These changes in the feldspar and the ferro-soda silicates could be explained by access of carbonated surface waters and metamorphic action. The color of the feldspar must be attributed either to the reduction of limonite particles or to the oxidation of magnetite.

At the Sartori quarry (p. 120) the feldspar has become largely kaolinized and micacized, and also somewhat stained with hematite. It has lost its translucence and acquired a dull greenish-brown hue. The black silicates have passed largely into an aggregate of biotite, magnetite, carbonate, and quartz and there are no minute riebeckite crystals in the feldspars.

At the Rogers quarry in West Quincy (p. 117) the feldspars at the south end and west side become a light olive gray after exposure. In thin section faint yellowish limonite stain appears along the rift and grain and along cleavage and irregular cracks. The yellow of the stain combined with the bluish green of the riebeckite yields an olive gray. In one section bright limonite stain is seen to ramify from the large particles of intergrown riebeckite and ægirite.

At several Quincy quarries some of the granite is spotted with deep cherry-red and muddy-olive stains up to an inch in diameter. These stains surround the larger riebeckite and ægirite particles from

[a] Van Hise, C. R., op. cit., p. 255.

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which they penetrate the adjacent feldspars. This discarded spotted granite is called "orel" by the workmen (p. 219). In thin section many of its feldspars are seen to be permeated by bright red hematite stain, which ramifies within them from the cleavage and rift cracks, as shown in fig. 4. This stain is also accompanied here and there by yellowish limonite stain probably of later date; and there are long slender particles, probably epidote, up to 0.33 by 0.0002 millimeter, which are all parallel in the same feldspar crystal. Radiating, needle-like, and fibrous felty crystals of secondary yellowish or muddy green hornblende are attached to the riebeckite and ægirite particles. Some of the ægirite crystals are completely altered to chlorite, magnetite, and quartz. The immediate cause of the staining of the feldspar and of the formation of the fibrous hornblende and possibly of the epidote is thus the alteration of the riebeckite-ægirite particles, but the cause of that alteration is not so apparent. Their alteration to magnetite, alone, implies metamorphism. At the Cashman quarry some "orel" was found next to a steep heading, and at the Hardwick quarry the granite within a heading has a hematitic color. These occurrences suggest that the change in the black silicates may have been brought about by access of surface water along joint planes, hydrating and oxidizing the iron of the silicates, and that the granite thus stained by limonite has become reddish as the limonite under metamorphism became reduced to hematite. It is also possible that, the black silicates having under metamorphism passed partly into magnetite, this may by oxidation have yielded hematite.

FIG. 4.—Thin section of altered Quincy granite (orel), enlarged 62½ diameters, showing hematite stain in the feldspar. The large particle from which streams of stain proceed is ægirite. Its altered parts are shaded.

This reddening of the feldspar also characterizes the gray quartz monzonite of two of the Milford, N. H., quarries (pp. 163, 166) for a thickness of 10 to 50 feet from its contact with basic dikes. The change takes place chiefly in the soda-lime feldspar, which is also much kaolinized. The source of this hematite is probably the magnetite particles.

CUT SURFACES.

Reference was made in Bulletin 313 (p. 59) to the fact that if one of two commercial "granites" of identical shade be a diorite, that is, a granite with only a soda-lime feldspar, and the other a normal biotite granite, that is, with very little of that feldspar and considerable potash feldspar, the cut surface of the diorite will be very

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much lighter than that of the normal granite; and it was pointed out that this is probably due to some optical property of the soda-lime feldspar. In the preparation of the material for this bulletin it has been found that the quartz monzonites of Westerly, R. I., and Milford, N. H., in which the soda-lime feldspar is in excess of the potash feldspar, cut lighter than normal granites even of lighter shade. Dr. G. P. Merrill suggests that the optical property involved here is the multiple twinning of the soda-lime feldspar which must greatly facilitate its breaking up under the hammer and thus increase the diffusion of light. As the dark purplish porphyritic rhyolite ("granite") of Montello, Wis., in which potash feldspar makes up half the rock and which has no other feldspar, hammers quite as light as the Westerly quartz monzonite, this shows that the same effect may be produced in some other way.[a]

GRANITIC QUARTZ, ITS TEXTURE AND COLORS.

The observations here brought together show that granitic quartz is far from possessing the homogeneous texture or color popularly attributed to that mineral. Not only is the quartz apt to contain cavities with and without vacuoles, as was shown on p. 42, in intersecting sheets related to rift and grain cracks, but it also contains minute opaque particles, particularly abundant in smoky quartz. Some of it abounds in hair-like crystals, probably of rutile. The quartz of some granites shows by its behavior in polarized light that the arrangement of its molecules has been disturbed by mechanical strain. In two Massachusetts granites, Milford and Quincy Gold-leaf quarry, this strain has been carried far enough to granulate the quartz. The granules generally measure under a millimeter in diameter. The quartz of the granites described in this bulletin varies from colorless to blue, amethystine smoky, rose colored, and smoky of various shades. At Redstone, N. H. (p. 182), an amethystine smoky quartz has become greenish by the coating of its rift and grain cracks with limonite. Colorless quartz has the fewest cavities or particles. The smokiness appears to be due to minute black particles. But the microscope fails to show the cause of the blue, rose, and amethystine tints.[b]

GRANITE DISCOLORATION AND ITS CAUSES.

In investigating the yellow-brownish discoloration, "sap," of the Maine quarries, thin sections showed that the limonite stain did not proceed from the ferruginous minerals and the inference was

[a] See Buckley, E. R., On the building and ornamental stones of Wisconsin: Bull. Wisconsin Geol. and Nat. Hist. Survey, No. 4, 1898, p. 94 and Pl. V.

[b] Rosenbusch, H., Mikroskopische Physiographie der Mineralien und Gesteine, 4th ed., 1905, vol. 1, pt. 2, Granit Quarz, pp. 93, 94.

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therefore drawn that it was due to the infiltration of ferruginous surface waters along the joint planes. (See pp. 35–36 and Bulletin 313, fig. 2.)

In the granites described in the present paper this limonitic stain occurs in varying thickness up to 2 feet. It is very abundant in the Rockport quarries, where its brightness has led to its architectural use. Thin sections of the Rockport "sap" show the stain along the boundaries of particles and in all cleavage and rift cracks as well as in streaks across them. It is conspicuous about hornblende and magnetite particles. The stain has also proceeded from the cracks inward into the intervening areas. The zonal arrangement of the rust stain is also noticeable. The medium gray of the fresh granite becomes at first greenish toward the surface; this is followed by a zone of deep yellow brown; and that in turn by a much lighter yellow brown. The greenish zone is that of advancing limonitization, the next of maximum stain, and the outside is that of delimonitization, or deoxidation due to organic acids, and made still lighter by the greater kaolinization of the feldspars of the surface. In some Rockport specimens this outer paler zone is covered by an extremely thin crust of bright yellow brown, as though a secondary infiltration of limonite had taken place after the deoxidation. Although in the Rockport granite the ferruginous minerals have furnished some of the stain, it is doubtful whether they could have supplied enough to color so many sheet and joint surfaces so intensely. A thin section of discolored Westerly granite also shows the rust stain arising from biotite and magnetite particles (p. 202).

A specimen of Quincy granite from the Dell Hitchcock quarry has a rim of "sap" from 1 to 1½ inches wide, of which the inner tenth to three-tenths are dark brown and the rest light brown. The inner boundary is very uneven, the rusty part having encroached upon the granite in roundish protuberances. Some of the limonite streaks start from ægirite particles. In a piece from the Wigwam quarry the stain proceeds from magnetite particles and not from the black silicates, but some of the magnetite particles are within crystals of riebeckite. In a specimen from the pea-green granite of the Lepage quarry, out of a rusty band 1½ to 2 inches thick, an inner one-fifth inch is deep brown, but the fresh granite next to it is dark greenish. The rest, or outer part, ranges from a very light brown to cream color at the surface. The stain proceeds from the black silicates and from the vicinity of zircon crystals, which are often associated with iron in some form. An ægirite crystal is one-half hematite. The central parts of others are altered to limonite before the outer.

The following shows how large a zone of discoloration small particles of magnetite may produce. In one of the fine-grained granites

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of Milford, N. H. (p. 170), there are occasional porphyritic crystals of black mica up to 1 inch long, 0.5 inch wide, and very thin, around which, after exposure, a circle of slight limonitic stain 20 inches in diameter appears on the rift surface. The stain has no appreciable thickness. The biotite probably contains, as usual, small particles of magnetite.

The conclusion from all these data is that the superficial discoloration of granite originates partly in the limonitization or rusting of particles of magnetite, biotite, or other black silicates by access of surface water, and partly also by the infiltration of ferruginous water along joint and sheet partings. These rusty rims often show three zones—an inner, in which the color is a mixture of that of the original granite and of limonite brown; a middle, in which it is exclusively limonitic, and an outer paler one caused by the deoxidation of the limonite by organic acids and the greater kaolinization of the feldspars.

As bearing on the time involved in this process, attention should be called to the very slight discoloration produced in the course of twenty-five years along a vertical blast crack in Quincy granite at the Dell Hitchcock quarry. Under the higher powers of the microscope a slight stain can be detected about the small epidote particles in the feldspars, and here and there along the boundaries of the quartz and feldspar.

OVOIDAL WEATHERING WITHIN A HEADING.

Shaler called attention to spheroidal weathering in the granite of Rockport,[a] and gave a plate showing "decomposition bowlders," which are the result of the progress of decay working inward from both sheet and joint surfaces. This is not unusual in granite regions. This decay is mainly due to the chemical processes described under "Decomposition" (p. 36). Spheroidal weathering in granite may, however, be partly of different origin. The writer many years ago made some colored sketches of a concentric cylindrical structure in granite at a railroad cut at Unter Brambach in Saxony, in which the surfaces an inch or two apart were coated with limonite stain. The cylindrical forms, although brought out by weathering, were apparently due to internal structure. Of like structural origin are also the concentric shelly spheroids of granite about an inner concretion of mica, a foot in diameter, described from central Bohemia by Jokély.[b]

Pl. VIII, *A*, represents an ovoid mass of extremely fine quartz monzonite (45 by 33½ by 25 inches) from the Redstone quarry, near Westerly, R. I. (p. 201). This mass came from a point 30 feet below

[a] Shaler, N. S., The geology of Cape Ann, Mass.: Ninth Ann. Rept. U. S. Geol. Survey, 1889, p. 567, Pl. LI.

[b] Jokély, Johann., Geognostische Verhältnisse in einem Theile des mittleren Böhmen: Jahrb. K.-k. geol. Reichsanstalt, vol. 6, 1855, p. 375 and figure.

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the surface within a heading 40 feet wide at the north end of the quarry, where much decomposition had taken place. As there are no indications at any of the Westerly quarries of an original spheroidal structure, this mass must be classed with those of Cape Ann, but the decomposition, instead of working on 5 sides of an exposed mass, has operated on the sides of a block formed by intersecting joints and sheets considerably below the general surface, and the egg shape is due to the unequal spacing of these partings.

DIKELIKE MASSES OF SCHIST IN GRANITE.

The dikes ordinarily occurring in granite are either granitic, including pegmatite, aplite, and granite proper, or basic. If a granite after the intrusion of such dikes be itself subjected to metamorphism so as to become schistose—that is, a gneiss—then these various dikes will also become more or less schistose. In the granite of Milford, Mass., however, there are schistose basic dikes without an equally gneissic or a parallel gneissic structure in the granite.

At the Cutting quarry (fig. 7) the west wall is formed by a vertical dikelike mass of biotite schist 2 feet thick striking N. 25° W. The east wall is formed by a heading of almost identical strike, N. 20° W., but dipping 70° E. As shown in the figure, neither of the flow directions nor the trend of rift or grain corresponds to the strike of the schist dike. The only corresponding structure is that of the heading and the inclosing walls of the dike. At the West quarry, 1½ miles southsouthwest of the last, there are two dikes of similar schist, one striking N. 67° W. and dipping 65° NNE., the other striking about N. 45° W. with nearly vertical dip. The nearest parallel structure is a joint striking N. 60° W. and dipping 47° SSW. At the Massachusetts Pink quarry, three-fifths mile southwest of the Cutting quarry, there is another schist dike, 2 feet thick, striking N. 3° W., and dipping 55° E. without other corresponding kinds of structure. The general schistosity of all these dikes is parallel to the joint faces which inclose them, and no merging between granite and schist was observed. Emerson and Perry (p. 73) note the rudely parallel films of biotite in the granite, which give it a gneissoid look, but which seem to be partly due to flow structure, and they note the undulatory extinction of the fractured quartz particles as showing a state of strain. The granular structure of the quartz areas is very noticeable on a polished face, and this very possibly resulted from the pressure which converted the dikes into schist.

In thin section the fine-grained dark greenish gray schist of the Cutting quarry dike is seen to consist of biotite, quartz, epidote in roundish grains from the alteration of feldspar and a little pyrite. The slightly more greenish schist of the dike at the second quarry consists of hornblende, quartz, biotite, epidote, and zoisite from altera-

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tion of feldspar, a brownish cloudy mineral (leucoxene?), and pyrite altered to limonite. Both are evidently altered dikes of mica diorite—that is, diorite schist.

Emerson and Perry regard these dikes as a "basic differentiate of the Milford granite" (p. 73).

It is evident from the facts given that whatever may have been the relation of the deep sources of the two rocks to which Emerson and Perry refer, the dike material was intruded between parted joints in the granite. It is also evident that the change of the eruptive into schist and the alignment of its particles with reference to the inclosing walls was brought about chiefly by compression which, although sufficient to metamorphose the dikes, affected the granite but slightly; nor was the vertical pressure sufficient to plicate the dike or its inclosing walls.

Thus a basic dike traversing a mass of granite in a highly inclined position may under lateral compression become schistose without the inclosing granite acquiring a corresponding schistosity.

RIEBECKITE AND OTHER MINERALS ON JOINT FACES.

Many granite joint faces are coated with secondary minerals. These minerals include hematite, pyrite, limonite, calcite, epidote, chlorite, stilbite, quartz, muscovite, etc. (See Bulletin 313, p. 51.) All these may owe their origin to alteration of the minerals of the granite, but where calcite occurs in considerable quantity, it probably came from originally overlying calcareous rocks.

Some of the joint and even sheet faces in the Quincy quarries are coated with a blue-black mineral with a peculiar sheen due to fibrous structure parallel to the face, and with a bluish gray streak. Such black faces can be seen at the Dell Hitchcock, the Field & Wild, the Granite Railway, and Rogers quarries and at the Mount Pleasant quarry in Milton (Pl. II). On one side of this last quarry both sheet and joint faces are thus coated, and at the Rogers quarry such black joint faces, spaced from 6 inches to 4 feet, make up a heading. These black joints are apt, however, to be intermittent, extending only a few yards or even inches at a stretch.

A thin section cut diagonally to one of these joints and its parallel subjoints shows six meandering or intersecting cracks from one-eighth to 1¼ millimeters apart, filled with crystals of riebeckite (a dark-blue soda hornblende), the smallest of which are 0.02 and the largest 0.1 millimeter long, together with fibrous white mica, limonite, and very little carbonate. The granite between these fissures is broken up here and there into minute angular fragments and the feldspar is granulated. The cement of this microscopic breccia is also riebeckite, the crystals of which lie with their axes either parallel to the fracture

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or across them or even projecting into the feldspar fragments. Some of the feldspars next to the joint are unusually crowded with riebeckite crystals, which probably originated in the same manner and at the same time as those within the joints.[a]

The secondary and relatively recent origin of this riebeckite is evident, and its formation by segregation from the ferro-soda silicates of the granite seems also quite probable.

Prof. James P. Smith has recently explained the alteration of a certain California arkose (decomposed granite or diorite) and a sandstone, with varying proportions of impure clay, into schists consisting largely of glaucophane (a soda hornblende closely related to riebeckite) as due to a process of recrystallization under heat and pressure.[b]

In the case of the riebeckite-coated joints and sheets of the Quincy riebeckite-ægirite granite some transfer of material into the joint spaces must also have taken place. The presence of this mineral on them shows that the granite of Quincy was subjected to a certain amount of metamorphism after the development of its sheet and joint structure.

Some joint faces at Milford and Becket, in Massachusetts, and Concord and Redstone, in New Hampshire, present different features. At the East quarry of Milford (p. 82) the parted joint which forms the west wall is filled with a fine-grained greenish brownish and cream-colored mass with transverse and longitudinal slickensided cracks. In thin section this proves to be a brecciated granite cemented with calcite, chlorite, fibrous muscovite, and limonite. The amount of calcite in this mass is so considerable that it seems improbable that the granite alone could have supplied it.

At the quarry of the Hudson & Chester Granite Company in Becket (p. 141) some of the joint faces of the bluish gray muscovite-biotite granite are dark greenish for one-fourth inch from the face. The granite in this zone has undergone these alterations: Formation of fibrous mica with limonite stain along cracks transverse to the face and along feldspar cleavages; formation of mica in the feldspars and of calcite both in the lime-soda feldspars and between the particles. These secondary minerals added to the original ones make these small rims quite complex.

At the "Upper or Granite Railway quarry" of John Swenson (p. 151) at Concord certain joints with a N. 65° W. course and short parallel subjoints are coated with minute quartz crystals and obtuse

[a] This and the occurrence of secondary riebeckite in rift and grain cracks, mentioned on p. 107, partly confirm the suspicion expressed by A. Sauer in 1888 as to the origin of this mineral. See Zeitschr. Deutsch. geol. Gesell., vol. 40, 1888, p. 145.

[b] Smith, James Perrin, Paragenesis of the minerals in the glaucophane-bearing rocks of California: Proc. Am. Phil. Soc., vol. 45, 1906, p. 183. See also summary, pp. 238, 240, 1907.

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calcite rhombs standing edgewise on the joint face, and also here and there with the beginnings of 2-inch cubes of deep purple and white fluorite. Similar fluorite occurs exceptionally within the granite near the face.

At the Redstone, N. H., quarry (p. 181) the light-pink granite for an inch back of one of the major joints is a yellowish pink with patches of grass-green, while the face itself is pale brick-red, rust color, bluish, and grass-green. Thin sections show the feldspars much altered to white micas, and crossed by veinlets of them. They are also kaolinized and stained pink by hematite from the magnetite particles. There is some carbonate, limonite, chlorite, and epidote.

While nearly all the secondary minerals in these joint coatings (chlorite, epidote, muscovite, hematite, limonite, calcite, and quartz) may be accounted for by processes of "deep-seated weathering"—that is, by the alteration, largely chemical, of the minerals of the granite itself—the fluorite is more likely to have been brought from the same source as the granite itself but at a later time, and the calcite of Milford from once overlying calcareous sedimentary beds.

GRANITE CONTACTS IN RELATION TO SHEET AND FLOW STRUCTURE.

Several interesting contacts between granite and its overlying rocks were found and are shown in fig. 5 and Pls. VI, *A*, and IX, *A*. These contacts throw light on the origin of sheet structure and illustrate the nature of flow structure and of certain pegmatite dikes.

CONTACT AT MILFORD, N. H.

At the southwest corner of the Pease quarry at Milford, N. H. (p. 163), about 6 feet of mica diorite gneiss overlies the fine-grained quartz monzonite, as shown in fig. 5, with a foliation striking N. 75° W. and a dip of 20° south. The granite has a flow structure about parallel to the contact surface, but sheet structure crosses both gneiss and granite and flow structure.

At the quarries, now idle (p. 173), of the Milford Granite Company there is a working face on the west about 1,000 feet long. At its southern and northern ends granite and gneiss contacts are finely exposed. The fine-grained quartz monzonite is overlain by about 15 feet of gneiss, with a foliation striking N. 75° W. and dipping 75° south. Pl. VI, *A*, shows the contact at the north end of the cut. The sheet structure is lenticular horizontal, but does not continue into the gneiss, which seems to have an independent and discontinuous sheet structure of its own. The gneiss varies greatly in texture, composition, and color. In places it is coarse, black, biotitic, and hornblendic; in others medium grained, gray or white, and more quartzose and feldspathic. It appears to be a quartz-mica diorite gneiss, but contains streaks of a finely banded, light-greenish, fine-grained rock, which in thin section shows quartz, soda-lime

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feldspar (oligoclase-andesine), augite, hornblende, and biotite, and thus appears to be a quartz-augite-diorite gneiss. There are also dikes of pegmatite starting from the surface of the granite and tapering out in the gneiss.

CONTACT AT NIANTIC, R. I.

At the Klondike quarry (p. 205) near Niantic, R. I., as shown in fig. 27, the fine-grained quartz monzonite is overlain on the west side by 50 feet of medium-grained biotite gneiss with porphyritic lenticular potash feldspars (microcline) up to 1½ inches long, most of them rimmed with white soda-lime feldspar (oligoclase-andesine). The foliation of this gneiss is about horizontal. As shown in Pl. IX, *A*, the contact between the granite and gneiss dips somewhat steeply, and sheet structure crosses both granite and gneiss at a lesser angle. There are also dikes of pegmatite beginning at the contact and tapering upward in the gneiss. On the east side the same gneiss underlies the granite, the granite intrusion having apparently reached

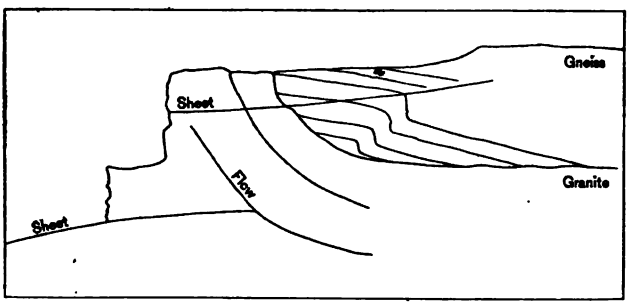

FIG. 5.—Section showing relations of granite and gneiss at the Pease quarry near Milford, N. H.; height, 10 feet. The flow structure is parallel to the contact surface, and sheet structure traverses both rocks.

at least the altitude of the present surface between two masses of the older gneiss; in other words, the original contact surface between the granite and the gneiss into which it was intruded was very irregular, having large denticulations.

CONTACT AT BECKET, MASS.

At the Becket, Mass., quarry (p. 141) a fine-grained, bluish-gray, muscovite-biotite granite partially incloses or is overlain by a mass up to 40 feet thick of very fine-grained, heavy, black, micaceous rock (quartz-mica diorite schist) described more fully on page 143. It has small white quartz and plagioclase veins of tortuous courses. There are also several small dikes of pegmatite or quartz starting from the contact and tapering out upward. Along the contact the granite shows undulating bands generally parallel to the contact surface. These consist of white bands of quartz and feldspar, up to one-fourth inch wide, recurring at intervals of 1 inch, the intervals

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being darker and of biotite, muscovite, epidote, and titanite. The courses of some of these bands are sharply undulate. These bands constitute a flow structure which generally conforms to the under surface of the diorite schist.

CONCLUSIONS.

In order to make these contact phenomena intelligible to the general reader, it should be stated that the gneisses capping the granite are rocks of similar origin to the granite itself, but they have been subjected to an amount of pressure and heat sufficient to recrystallize their minerals and arrange them in parallel order, thus giving the rock a foliation or schistosity; also, the present thickness of the overlying gneisses probably represents but an insignificant part of the great masses which originally capped the granite. From the fact that the granite has not been changed in like manner, it follows that these changes must have taken place before the intrusion of the granite. The pegmatite dikes are granitic matter which in a molten condition or in heated solutions appears to have forced its way from the molten granite through fissures caused by the intrusion itself into the overlying gneiss.

The geological principles illustrated by these various contacts are: (1) Sheet structure in granite can not be the result of any property inherent in the granite alone, for it passes uninterruptedly from the granite into the overlying gneiss, and it is also quite independent of flow structure; (2) the course of flow structure in granite is governed in places by the form of the under surface of the masses into which the granite was intruded. Thus also at the Daniels quarry, in Milford, N. H. (p. 168), it accommodates itself to the form of a large inclusion, forming bands around it; (3) pegmatite dikes are apt to originate at the surface of the granite and to penetrate the rock into which it was intruded.

These pegmatite dikes were not studied in sufficient detail to obtain conclusive evidence that the pegmatization of the gneiss could not have taken place in an earlier crustal movement than that of the granitic intrusion.

ACIDIC SEGREGATIONS.

Segregations in granite consist generally of the darker, more ferruginous minerals, but in some instances they are lighter in shade than the surrounding granite and consist largely of feldspar and quartz, as are several at the Quincy quarries, described on page 95. Here also belongs the very coarse-grained large segregation found in the Rockport granite at Halibut Point, which is fully described on page 125. Although it measures 8 by 4 by 2½ feet, all but a core, 6 by 2 inches, which is bronzite, consists of potash feldspar and quartz.

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PART II.—ECONOMIC DISCUSSION.

GENERAL FEATURES.

The practical side of the granite industry will now be considered. A list of the more important works on granite quarries and quarrying and other matters of economic character will be found at the end, together with a glossary of both scientific and quarry terms.

TESTS OF GRANITE.

The testing of granite is a subject of considerable importance, as may be seen by its literature.[a] As pointed out by Merrill, there is danger of attaching undue importance to tests of compressive strength alone, the results of which in nearly all cases far exceed the generous margin allowed by architects beyond that required by the weightiest structures. On the other hand, there is danger of losing sight of several other important qualities which ought to be carefully tested and upon which the economic value of granite in part depends. The following tests include all the kinds made at European testing institutions or recommended by American authorities, as well as some suggested by the investigation of Maine granites.

Chemical analysis.—Chemical analysis is made in order to determine the amount of iron and lime, or to detect anything abnormal in the composition.

Determination of $CaCO_3$.—Tests are made to determine the presence of lime not combined with silicates in order to ascertain the percentage of $CaCO_3$ (lime carbonate) present. This is done by powdering and treatment with warm dilute acetic acid.

Test for discoloration.—The method applied by Daly (Bull. U. S. Geol. Survey No. 209, p. 52) seems to be well adapted for this purpose. A piece of fresh rock is immersed in a stream of carbon-dioxide gas for 20 minutes and then kept in an atmosphere of that gas for 24 hours. Another piece of fresh rock is placed in an atmosphere of purified oxygen overnight and then exposed for 30 minutes to a temperature of 150° C. (302° F.). Any discoloration due to the carbonization or oxidation of the minutest particles of any mineral would be sure to show itself under these tests.

Mineral composition.—This is determined by the microscopic examination of a considerable number of typical thin sections. All the mineral constituents are noted, and the average size of the mineral

[a] See Bibliography, p. 215.

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particles in the case of the fine-textured granites is estimated. Any peculiarities of texture, rift, etc., can also be noted.

Proportions of minerals.—A method has been devised by Rosiwal, of the Austrian Geological Survey,[a] by which the approximate proportions of the chief minerals (feldspar, quartz, mica, hornblende and their average size can be determined. This consists in tracing a network of lines intersecting one another at right angles upon a polished granite surface, at intervals so far distant that no two parallel lines will traverse the same mineral particle. The total length of the lines is measured, then the diameters of all the particles of each kind of mineral are added separately and their proportion to the total length of the lines obtained. The average size of the particles of each mineral can be also calculated from the same measurements. Although this method was primarily designed for application to the coarse and medium granites, it can be extended also to the finer ones by drawing the lines upon camera-lucida drawings made from thin sections of such granites under polarized light. As the quartz is the source of the vitreousness of the rock the determination of its amount is important. The incompleteness of the collection of polished specimens of Maine granites and the short limit of time available prevented the application of this method in the preparation of the report on Maine granites, but the method was experimentally applied to the coarse reddish granite from Hardwood Island, near Jonesport,[b] and has been much used in this bulletin.

Polish.—Besides the manifest object of this test it also facilitates exact descriptions of color and comparisons between different granites. The size of the mica plates determines the brilliancy and durability of the polish more than does their number—that is, a considerable number of very minute mica plates is not objectionable.

Hardness.—As pointed out by Hawes,[c] the hardness of certain granites is not due entirely to the quartz, which is always equally hard and brittle and which the tools do not cut but crush, but to the feldspar, which is of variable hardness and, it might be added, has different cleavages, and the proportion of which in relation to quartz also varies. Rosiwal,[d] adopting a principle established by Toula, takes a piece of smooth unpolished granite of about 2 grams weight and rubs it with emery (of 0.2 mm. diameter of particle) upon a glass or metal plate for 6 or 8 minutes until the emery loses its

[a] See Rosiwal, August, Ueber geometrische Gesteinsanalysen; ein einfacher Weg zur ziffermässiger Feststellung des Quantitätsverhältnisses der Mineralbestandtheile gemengter Gesteine: Verhandl. der K.-k. geol. Reichsanstalt, vol. 32, pp. 143–175.

[b] The result of this test is given on page 173 of Survey Bulletin 313.

[c] Hawes, G. W. (edited by Merrill), Granite; Building stones of the United States and statistics of the quarry industry: Tenth Census, vol. 10, 1888, pp. 16–18.

[d] Neue Untersuchungsergebnisse über die Härte von Mineralien und Gesteinen: Verhandl. K.-k. geol. Reichsanstalt, 1896, p. 488.

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effectiveness. The granite is then weighed again and its loss of volume calculated. He found, assigning to emery an arbitrary value of 1,000 as representing its average hardness, that granite from 9 localities showed the following degrees of hardness: 31.7, 38.1, 41.7, 44.8, 48.4, 50.7, 52.9, 56.6, and 67.1. The extremes of these figures show that some granites have a general hardness more than twice as great as others.

J. F. Williams[a] proposed to determine the relative hardness of granites by noting the rate of penetration of a drill of a given diameter, or by measuring the distance to which such a drill will penetrate without being sharpened, or the amount of surface of rough-pointed granite which can be reduced to a bush-hammered surface per hour. Since the introduction of pneumatic drills and surfacers these methods can be easily applied.

Compressive strength.—The methods of testing the strength of building stones have grown in precision. The first requisite is that the cubes to be tested should be sawed by diamond saws and not hammered out. The next is that the direction of both rift and grain should be indicated thereon, and that three cubes should be tested, one with pressure applied parallel to the direction of the rift, one applied parallel to that of the grain, and the third at right angles to rift and grain. Where the rift and grain are pronounced the three results will differ. As in the reports of tests made with the testing machine at the Watertown Arsenal, Mass., the number of pounds pressure at which the first crack is produced should always be given, as well as that at which the cube is crushed. It is assumed that these tests are made in a dry atmosphere.

Transverse strength, shearing strength, and compressive elasticity.—It has been found useful for certain architectural purposes to test these qualities in granite.[b]

Porosity.—Buckley[c] points out that the danger from frost depends not upon the amount of absorption but upon the size of the pore space. Rocks with large pore spaces stand frost better than those with small ones, because they do not retain the water that they absorb. Tests of porosity are therefore important. Buckley used the dry and saturated weights obtained for the samples used in computing the specific gravity.

The difference in these weights was multiplied by the specific gravity of the rock. This amount was added to the dry weight, giving the sum. The difference of the dry and saturated weights multiplied by the specific gravity of the rock was then divided by the sum. This last result is the actual percentage of pore space compared with the volume of the sample tested.

[a] Igneous rocks of Arkansas: Ann. Rept. Geol. Survey Arkansas, vol. 1, 1890, p. 41.

[b] See Buckley, Building and ornamental stones of Wisconsin, pp. 396–398. Also Rept. of tests of metal, etc., Watertown Arsenal (1895), 1896, pp. 319–322, 339–351, 407–411. Some of the results as to elasticity are given on page 16 of this report.

[c] Buckley, op. cit., pp. 68, 69, 372–376, 400, 413.

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Freezing and thawing.—Buckley's method[a] consists in drying 1-inch and 2-inch cubes at a temperature of 110° C. and weighing them. After being saturated in distilled water they were exposed overnight to a temperature below freezing. They were then thawed out and soaked in warm distilled water. This process was continued for thirty-five days, when they were again dried at 110° C. and weighed. Finally the same stones were subjected to the tests for compressive strength and the results compared with those for stones not thus treated.

Absorption and compression.—The complete saturation of a stone and the determination of the amount of absorption are effected by a method described at length by Buckley.[b] The saturated stone should then be tested for compressive strength and the result compared with that obtained from dry stone.

Behavior under fire.—This test is best applied to saturated specimens, which are then exposed in a laboratory furnace to a temperature up to 1,500° F. and the effect noted. Some of them can be allowed to cool gradually, but others should be immersed quickly in cold water; or they may be exposed to high temperature while under compression and then cooled slowly or quickly.[c]

Specific gravity.—The specific gravity is the weight of the stone at 16° C. compared with that of the same volume of distilled water at 4° C. All air should first be removed from the piece to be tested by boiling in distilled water. The specific gravity is also required for the test of porosity.

Weight per cubic foot.—The weight of the dry stone per cubic foot is obtained by multiplying its specific gravity by the weight of a cubic foot of water, but from this there should be deducted "the weight of a quantity of stone of the same specific gravity equal in volume to the percentage of the pore space in the stone."[d] This gives the actual weight of the stone free from interstitial water.

Coefficient of expansion.—Finally, it may be desirable to obtain the coefficient of expansion of a granite intended for some particular construction. The expansion of certain granites was determined at the Watertown Arsenal by hot and cold water baths. The stones thus tested were afterwards subjected to the test of transverse strength, when it was found that they had lost 16.93 per cent of their original strength.[e]

A list of the various tests applied to building stones by German testing institutions is given by Herrmann.[f]

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[a] Buckley, op. cit., p. 71.
[b] Buckley, op. cit., pp. 64-67.
[c] Buckley, op. cit., pp. 73, 411.
[d] Buckley, op. cit., p. 70.
[e] Rept. of tests of metal, etc., p. 320.
[f] Steinbruchindustrie und Steinbruchgeologie, pp. 10. et seq.

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ADAPTABILITY TO DIFFERENT USES.

The successful use of granite depends upon a careful consideration of its various adaptabilities. The granites proper include stones which vary greatly in texture, color, and shade. The coarse-textured ones are best adapted to massive structures, while the fine-textured ones are better adapted to lighter structures, monuments, and statues. The reason for this is that in coarse-textured granites the large feldspars crossing the various sculptural designs at all angles produce lines and reflections that interfere with the lights and shades produced by the sculptor's design, and thus mar their effect. The fine granites are well adapted to light structures and to fine sculpture, as is shown in the delicately carved granite flowers represented in Pl. IX, *B*. Some coarse granites, however, lend themselves well to coarse carvings, especially when these are to be placed in the higher parts of buildings. Then there is the matter of color and shade. There is large room for the exercise of artistic taste in deciding which colors and shade will best harmonize or contrast with one another in a granite structure or with the colors of other stones or materials in a composite structure. The rust-colored "sap" of Rockport has been used successfully for trimming in connection with the fresh gray granite of that place, on account of the resulting contrast (p. 125). There is also room for choice between different granites in ornamental work, because of the different amount of contrast between the polished, hammered, and rough surfaces of stones of different color and texture, although the polished surface is always darkest and the hammered lightest. The black granites and the quartz monzonites are obviously best adapted for inscriptions where legibility at a distance is the prime object, and also for all ornamental work in which more marked contrasts are desired than the ordinary granite can furnish. The black granites are sometimes combined with ordinary granite of light shade in monumental work, the die being of black granite. Some granites are noted chiefly for their high polish and its durability, and are therefore in demand for columns and wainscoting.

ECONOMIC FACTORS IN GRANITE QUARRYING.

The factors upon which the successful operation of a granite quarry depends are various. The first are petrographical and geological. These include (1) the mineral composition and texture of the rock and its physical properties; (2) its structural features—that is, the directions of the flow structure, rift, and grain, compressive strain, and contact surface with overlying or adjacent rocks of other kinds; (3) the character of the sheet structure, of the jointing, and of headings, dikes, and veins; (4) the size and number of inclusions

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and "knots," and (5) the thickness of the rusty rims of sheet and joint surfaces. The economic importance of minute structural features, such as the great variation in its fissility, is exemplified in the range of the number of paving blocks which equally skilled workmen can make of different granites in one day. Thus at Quincy a paver averages 75 blocks a day (size, 12 by 8 by 4 inches). In Maine the number is from 80 to 100 of New York size (11 to 14 by 7 by 4 inches). At Milford, N. H., the average number of Philadelphia size is 200, and at Redstone, N. H., 130 of New York size, which is from 33 to 50 per cent more than is usual in Maine. At Becket (Chester), Mass., the average is 150, size not stated. Another geological factor is the "stripping" or amount of surface material, sand, etc., to be removed from the granite surface.

Other factors, such as facilities for drainage and water supply, the location of the quarry with reference to transportation facilities by land and water, and the disposal of waste, are hydrographical and geographical.

Then there is the artificial factor: The equipment of machinery for pumping, drilling, hoisting, loading, and transfer to car or ship. In the larger quarries this includes air compressors and air drills and in places stone crushers for the utilization of waste.

But when all these factors are satisfactory, success will still largely depend upon the experience and judgment of the foreman or superintendent who directs the blasting and splitting. Without his intelligent control, suitable stone, favorable natural conditions, adequate capital, equipment, and labor are of little avail. The selection of the place for blasting, the size and shape of the hole, the selection of the powder, and the size of the charge are all matters requiring careful consideration. The thickness of the sheet, the proximity of joints, the vitreousness of the stone, its rift and grain structure, the physical laws governing the action of explosives, and the direction in which the quarryman desires to split the mass are all factors in each problem.

The principles of rock blasting are set forth mathematically in a recent book by Daw,[a] and a general description of quarry methods will be found in a report by Walter B. Smith.[b]

The practice of foremen in the thirty principal granite quarries of Maine, as explained by them to the writer, is described in Bulletin 313, pages 69–71.

In visiting the quarries described in this bulletin a few notes on the use of explosives were made, which are here summarized.

[a] Daw, A. W. and Z. W., The blasting of rocks in mines, quarries, and tunnels, etc., pt. 1, London, 1898.

[b] Methods of quarrying, cutting, and polishing granite: Mineral Industries; Eleventh Census, 1892, pp. 612–618; also Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 4 (1894–5), pp. 446–456.

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Although the general practice in the Massachusetts, New Hampshire, and Rhode Island quarries is essentially the same as in the Maine quarries, yet in some localities, owing to different conditions of rift, grain, and strain, other modes prevail, as in the following quarries:

Becket (Chester) quarry.—Blasting along a vertical grain, which is pronounced, with a free face and one free side is found to work successfully.

Milford, Mass., quarries.—Blasting along a feeble grain or the hard way, but preferably along the former, with one free face and a free side.

Quincy quarries.—Blasting along the grain parallel to the free face and with a channel on one side parallel to the rift.

Rockport.—(1) Blasting along the rift parallel to a free face and with one free side. But the lewis holes extend at least three-fourths of the distance from the free side to prevent the crack slanting to the face. (2) Blasting along the hard way parallel to the free face and with one free side. The crack slants away from the face, if at all. In one place 15 contiguous knox holes 35 feet deep, along the rift, which dipped 75° to 80°, were blasted with a free face and one free side. By this means a block 125 by 60 by 40 feet deep was loosened.

Concord.—Blasting along a north-south hard way parallel to a free face 30 feet long, with both ends tight; then channeling along the east-west grain on one side, and blasting with knox holes on the other. The hard way blast proves effective, it is thought, because of a compressive northwest-southeast strain. In other places blasting along the grain with two free sides, or, if that is not practicable, with one only.

Redstone, N. H.—Blasting along the grain, which is marked, with one free face and one free side.

Milford, N. H.—Where rift and grain are feeble, blasting in any direction with a free face and one or no free side.

Westerly.—Blasting along a north-south hard way parallel to a free face and with one free end, thus utilizing a strain which operates east-west in the direction of the grain. Very little powder is used in the fine-grained Westerly granites, owing to their delicacy.

A difference is found in blasting and splitting granite in winter and summer. A low temperature increases its cohesiveness, but, probably in connection with water, increases its fissility where the "rift" is feeble.

It is reported that in quarries in Finland the expansive power of freezing water is regularly used in splitting. This is in line with the ancient Egyptian use of the expansion of wet woody tissue. A

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method of blasting in use in some of the English coal mines by means of the expansion of slaked lime may be susceptible of adaptation to the quarrying of the more delicate granites.[a]

In this connection should be mentioned the method, recently adopted in the granite quarries of North Carolina, of developing an incipient sheet structure by the use of high explosives followed by the application of compressed air. (See footnote *b*, p. 28.)

METHOD OF DESCRIBING THE QUARRIES.

The quarries of the granite centers visited in Massachusetts, New Hampshire, and Rhode Island will now be described. Those of each center will be prefaced with a brief reference to the general geology of the region and also with an outline of its typical granites. The particulars as to each quarry will be taken up in the following order:

1. Name and location of quarry; name and office address of operator.

2. The granite—its trade and technical names, color, texture, and minerals; its mineral percentages estimated by the Rosiwal method as explained on page 66; its chemical composition and physical qualities as shown by any available analyses or tests. The words "coarse," "medium," and "fine," as applied to texture, are to be understood as in Bulletin 313, and as defined on page 14 of this bulletin: Coarse, having feldspars generally over two-fifths inch or 1 centimeter; medium, having feldspars under that and over one-fifth inch or one-half centimeter; and fine, having feldspars under one-fifth inch.

3. The quarry, with date of its opening and size.

4. The rock structure, comprising sheets, joints, headings—their strike, dip, and thickness—rift and grain, flow structure, dikes, veins, "knots," discoloration, and weathering. Where the structure is complex a diagram is given.

5. The plant, with the number of machines and air tools to show its capacity.

6. Transportation, including distance to dock or railroad and method of transport.

7. The product, its uses, with names and location of a few specimen buildings or monuments.

[a] See Mosley, Paget, On a new method of mining coal: Jour. Iron and Steel Institute, London, 1882, pp. 53–62.

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SPECIAL FEATURES.

DESCRIPTIONS OF THE GRANITES AND QUARRIES.

MASSACHUSETTS.

MILFORD.

Topography.—Milford lies in the eastern half of Massachusetts, in Worcester County, 16½ miles southeast of Worcester. (See map, Pl. I.) It is a region of low hillocks with northerly, northeasterly, and northwesterly trends. The quarries, as shown in fig. 6, lie between N. 10° W. and N. 45° E. of Milford. Two are in Hopkinton, in Middlesex County, and twelve in the town of Milford. All are between the 300 and 500 foot levels.

General geology.—The granite of Milford has, under the name "Milford granite," been classified by Emerson and Perry as post-Cambrian.[a]

They represent an area of it extending from Woonsocket, R. I., south to beyond the southern boundary of Providence County, a distance of about 21 miles. They have traced a diorite, in places a diorite schist, entirely around the granite of Milford, and regard it as a "basic differentiate of Milford granite."[b] By this term is intended a basic eruptive originating in the same source as the granite, but either succeeding or preceding the intrusion of the latter. If this diorite preceded the granite it has no relation to the diorite dikes which traverse it. The fine-grained white quartzite (metamorphic sandstone) which crops out 3 miles north of Milford on the road to Hayden Row is regarded by these geologists as of Cambrian age and belonging to the "Grafton quartzite," of which there are several areas in Rhode Island along Blackstone River, also west of Providence. It is thus older than the granite.

Emerson and Perry describe "Milford granite" in these words:

> A great granite area of a constant type that extends across Massachusetts and Rhode Island in the western part of the area here studied has been named by the writers from the well-known quarries in Milford, Mass. This is a compact, massive rock, somewhat above medium grain, and of light color. The light flesh color of the feldspar and the blue of the quartz give it in some places a slight pinkish tint, and it is now much used as a structural stone under the name "pink granite." Its two especially characteristic constitutents, constantly present, are blue quartz and a microcline microperthite, in which albite is always dusted with minute crystals of muscovite and epidote, especially centrally, while the microcline is free from these minerals. These perthitic bands of albite also generally extend out beyond the surface of the microcline, and cover it with a more or less continuous veneer. The rock also shows a fine micrographic structure in contact with quartz. The feldspars project idiomorphically into large fields of quartz, which seem to have been single grains, but are now somewhat cracked. Most of this quartz is blue, and this color appears also in the contact zones and even in the second-

[a] Emerson, B. K., and Perry, J. H., The green schists and associated granites and porphyries of Rhode Island: Bull. U. S. Geol. Survey No. 311, 1907, Pl. I.

[b] Personal letter from Professor Emerson dated May 1, 1907.

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ary quartz that is found in fragments of schist which are inclosed in the granite and which have been greatly altered by it. The fractured grains of quartz show with

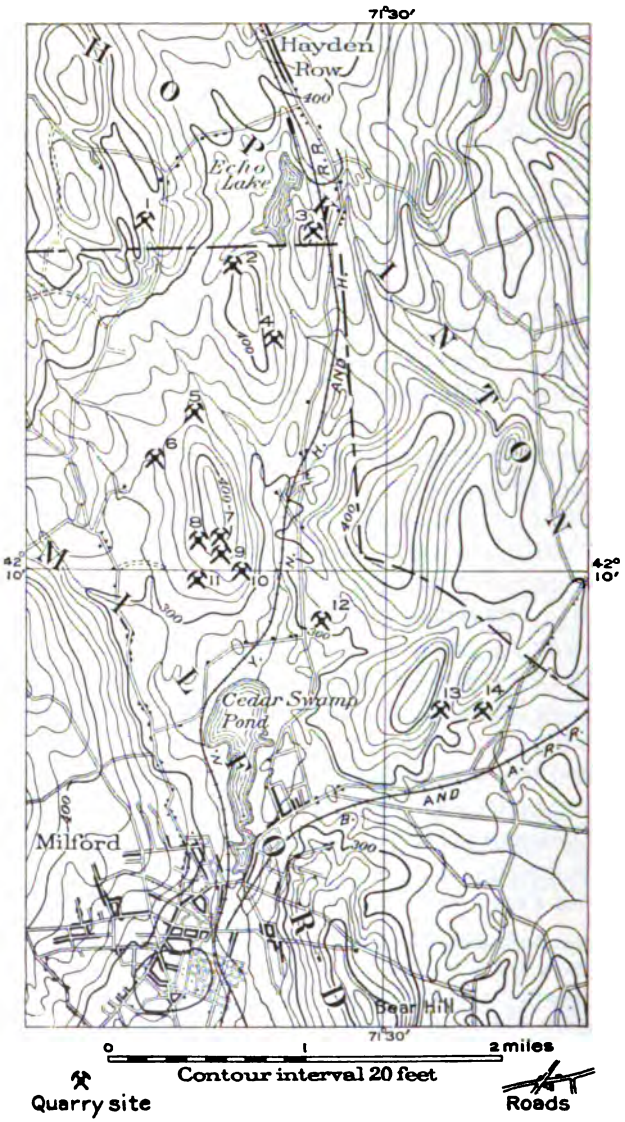

FIG. 6.—Map of Milford, Mass., showing locations of granite quarries. 1, Maguire quarry, Norcross Milford Pink Granite Company. 2, Echo Lake quarry, same company. 3, Hopkinton quarry, Massachusetts Pink Granite Company. 4, Cutting quarry (Milford Stone Company, in 1906). 5, Massachusetts Pink quarry, Massachusetts Pink Granite Company. 6, North Milford quarry, North Milford Granite Company. 7, Quarry No. 8, Webb Pink Granite Company. 8, Quarry No. 7, Webb Pink Granite Company. 9, Quarry No. 5, Webb Pink Granite Company. 10, Quarry No. 3, Webb Pink Granite Company. 11, Quarry No. 4, Webb Pink Granite Company. 12, West quarry (Milford Stone Company, in 1906). 13, East quarry (Milford Stone Company, in 1906). 14, Norcross quarry (Milford Stone Company, in 1906).

polarized light the strongest undulatory extinction, which indicates a state of strain that has probably produced the blue color. The biotite is in small amount, and is

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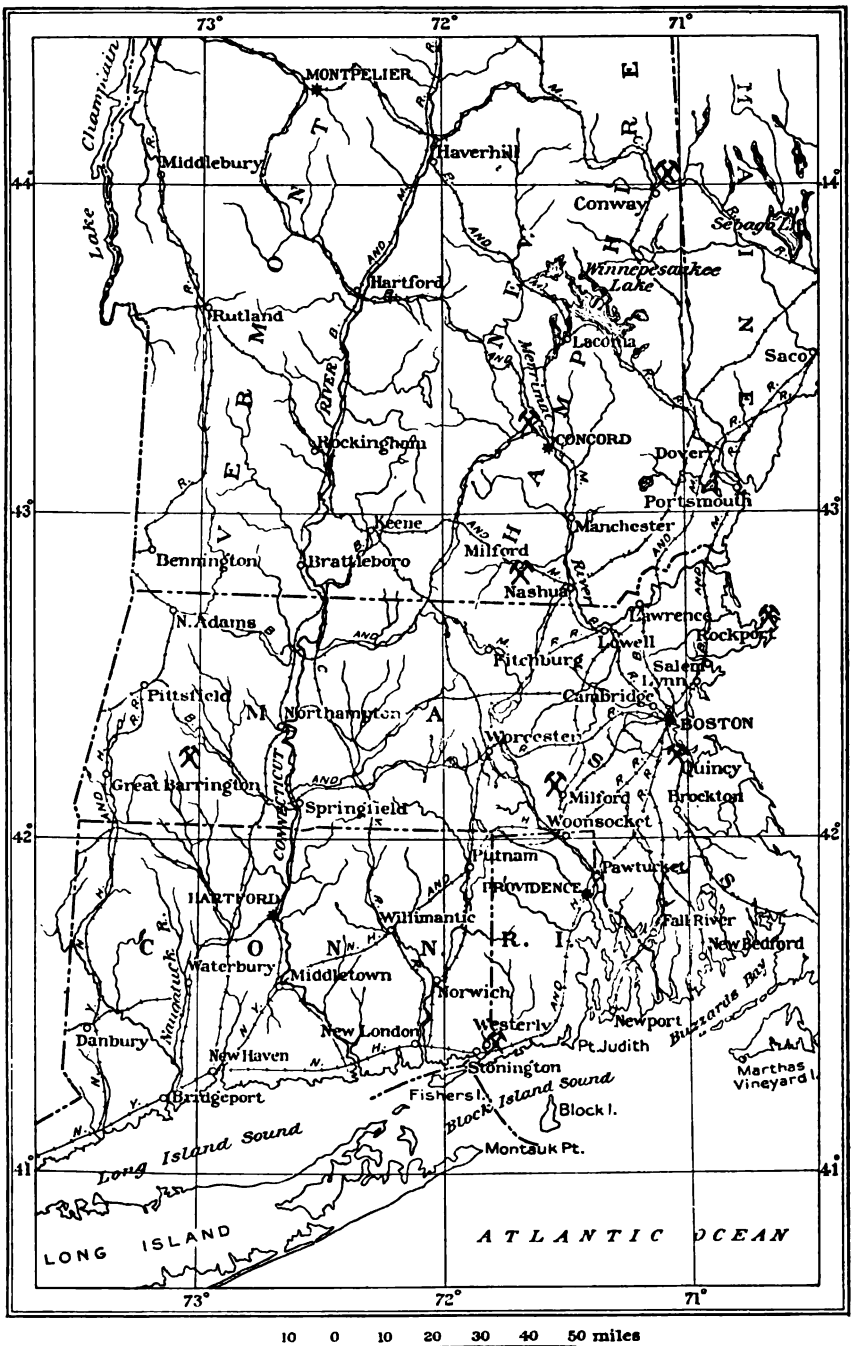

MAP OF PART OF NEW ENGLAND, SHOWING GRANITE CENTERS DESCRIBED.

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here and there associated with epidote grains. In specimens of granite taken at the quarries at Graniteville it is evenly distributed or gathered in small blotches, as in the Milford type, and the rock in these quarries can hardly be distinguished from the Milford granite. In the northwest portion of the area, near Woonsocket, the biotite occurs in distant, interrupted, rudely parallel films, as in the rock at the Fayville quarries north of Milford.[a]

Description of Milford, Mass., granite.—The following epitomizes the descriptions of rough and polished specimens and thin sections of granite given beyond. Analyses and tests are also summarized. Milford granite is a biotite granite. Its general color ranges from a light gray or light pinkish gray to a medium slightly pinkish or pinkish and greenish gray, but always with spots rich in black mica from 0.2 to 0.5 inch across and in some cases tapering out to an inch in length.

Its texture varies from medium to coarse, not porphyritic; but, owing primarily to a marked flow structure and secondarily to compression, there is some alignment of particles, giving the stone a slightly gneissoid appearance. The feldspar, quartz, and biotite are each apt to form continuous lenticular areas up to an inch in length. On the polished face the quartz is seen to be finely granular. The general appearance of the stone varies according to the relation of the direction of the cut face to that of the flow structure. Whenever the plates of black mica, which lie with their major axes in the plane of the flow structure, coincide with the face of the stone, it will show much larger black spots than when the face intersects that plane at right angles.

Its constituent minerals, in descending order of abundance, are (1) a more or less delicate pink, rarely cream-colored, potash feldspar (orthoclase and microcline), minutely intergrown with soda-lime feldspar and in places somewhat kaolinized; (2) faintly blue quartz fractured into particles up to 1.75 millimeters, in some specimens not over 0.75, showing some arrangement of cavities in sheets and in places with hair-like crystals presumably of rutile; (3) a slight yellowish green to milk white, rarely clear, striated soda-lime feldspar (albite to oligoclase-albite). When this feldspar is not clear it abounds in minute crystals and particles of epidote and zoisite, scales of white mica, and some chlorite and kaolin. The last constituent is biotite (black mica), some of it chloritized and associated with epidote. The accessory minerals are garnet, pyrite, magnetite, ilmenite, zircon, allanite,[b] usually rimmed with epidote, and apatite. The secondary minerals are kaolin, white mica, epidote, zoisite, calcite (usually in the soda-lime feldspars), titanite (about probable ilmenite in biotite), and hematite. There is some radiate intergrowth of quartz and feldspar.

[a] Op. cit., pp. 45, 46.
[b] See glossary.

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The color of the stone is governed mainly by its feldspars, pink from the potash and green from the soda-lime feldspar. These are but very slightly modified by the pale-bluish tinge of the quartz.

The somewhat gneissoid arrangement of the minerals, giving the feldspar and quartz particles uncertain boundaries in the direction of the flow, prevents the accurate application of the Rosiwal method,[a] which provides that no one particle should be crossed more than once by lines parallel. A specimen from quarry No. 8 of the Webb Pink Granite Company, in which there is little if any flow structure, contained the following percentages:

Estimated mineral percentages in Milford, Mass., pink, even-grained granite.

Feldspar	55.91
Quartz	35.66
Biotite	8.43
	100.00

Five tests on three specimens of the more gneissoid granite showed the following ranges:

Estimated mineral percentages in Milford, Mass, pink gneissoid granite.

Feldspar	49.92–70.88
Quartz	23.04–41.08
Biotite	4.72–11.29

These variations are due partly to the very different proportion of biotite on the different faces of the rock, as already explained.

Three complete analyses of this granite, made by L. P. Kinnicutt and R. H. Richards, are given under the respective quarries. They show these extremes:

Extremes of analyses of Milford, Mass., granite.

SiO_2 (silica)	72.02–77.08
Al_2O_3 (alumina)	12.54–14.43
FeO (iron oxide)	.52– .95
Fe_2O_3 (iron sesquioxide)	.00– 1.25
MnO (manganese oxide)	.24– .33
CaO (lime)	.75– 1.18
MgO (magnesia)	Trace– .01
K_2O (potash)	4.99– 5.41
Na_2O (soda)	3.64– 5.85

The following analysis of the granite from one of the Norcross Brothers quarries was made by Prof. C. F. Chandler, of Columbia University:[b]

[a] See for details p. 66.

[b] Day, Wm. C., 29th Ann. Rept. U. S. Geol. Survey, pt. 6, continued, 1898, p. 221.

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Analysis of Milford, Mass., granite.

SiO_2 (silica)	76.07
Al_2O_3 (alumina)	12.67
Fe_2O_3 (iron sesquioxide)	2.00
MnO (manganese oxide)	.03
CaO (lime)	.85
MgO (magnesia)	.10
K_2O (potash)	4.71
Na_2O (soda)	3.37
	99.80

Mr. E. C. Sullivan, a chemist of the United States Geological Survey, extracted, by means of hot dilute acetic acid, 0.06 per cent of CaO (lime) from an average specimen from the Cutting quarry. This lime was thus present in the form of $CaCO_3$ or calcite (lime carbonate) to the extent of 0.107 per cent, its presence being recognizable also under the microscope. It probably was formed from the decomposition of the lime-soda feldspar.

Six crushing tests made at the United States arsenal at Watertown show an ultimate strength of 20,000 to 29,200 pounds per square inch for Milford granite.

Those sections of the stone in which mica is least abundant take a good polish, but the others are not likely to preserve their polish in prolonged outdoor exposure. The scarcity of pyrite and magnetite on the polished face is very noticeable.

Geology of Milford, Mass., quarries.—The diorite schist dikes which traverse this granite have already been described on page 59, and the probable connection between the development of schistosity in these dikes and the stress which granulated the quartz of the granite has been pointed out. There are also dikes of aplite from half an inch to 4 feet thick, some of it a quartz monzonite in composition, and dikes of porphyritic granite with N. 10° and 35° E. and N. 20° W. courses. Some of these contain elliptical biotitic segregations (or inclusions?).

The flow structure strikes N. 10°, 35°, 40°, 45° W. and N. 77° E., dipping from 40° E. to 90°. In places it is nearly horizontal.

There are inclusions of biotite gneiss or mica diorite from a few inches to 2 feet thick, showing that this rock overlay or adjoined the granite at the time of its intrusion.

The rift is reported as everywhere horizontal and the grain as vertical with a N. 40° E. to an east-west direction. Rift and plane of flow structure are in places nearly parallel.

Sheets from 6 inches to 18 feet thick are generally irregular or undulate horizontally with inclinations up to 20°.

As will be seen from the quarry diagrams, there is a wide range in the joint courses. They are N., N. 10°, 20°–25°, 45°, 50°, 60° E.,

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and N. 60°, 70°, 80° W. Those occurring at the largest number of quarries are N. to N. 10° E., N. 45°–60° E., and N. 55°–70° W. The filling of a parted joint with calcite probably derived from once overlying calcareous rocks has been noted on page 61.

The Milford, Mass., quarries.—The Cutting quarry is in Milford Township, 3 miles N. 5° E. of Milford and half a mile south of Echo Lake (fig. 6). Operator in 1906: Milford Stone Company, Milford, Mass.[a]

The granite (specimens D, XXVIII, 13, a, b, c) is a biotite granite of light-gray shade, with a very slight pinkish tinge and conspicuous black spots. Its texture is somewhat gneissoid, medium to coarse, with particles up to about 0.5 inch. In faces cut parallel to the plane of flow structure the black spots measure fully 0.5 inch, but when cut in the transverse direction about 0.3 inch. The quartz areas are always granular, the particles up to 1 millimeter in diamter and exceptionally 1.5 millimeters. The rock consists of the following minerals, in descending order of abundance: A very delicate pink potash feldspar (orthoclase and microcline, both with minutely intergrown soda-lime feldspar); quartz with minute cavities arranged in sheets, appearing colorless in isolated particles, but in the aggregate having a very pale bluish tinge; a milk-white to pale-greenish striated lime-soda feldspar (albite to oligoclase-albite), usually crowded with particles and crystals of epidote and zoisite from 0.0094 to 0.076 millimeter in length; biotite (black mica), some of it altered to chlorite and associated with epidote. Both feldspars are somewhat kaolinized, particularly the soda lime. The accessory minerals are: Garnet, rare pyrite and magnetite, titanite, zircon, allanite crystals up to 1 millimeter long, coated with epidote, and apatite. The secondary minerals are: Kaolin, epidote, zoisite, chlorite, calcite, and hematite.

An estimate of the mineral percentages with half-inch mesh and total linear length of 45.5 inches yields:

Estimated mineral percentages in Milford, Mass., pink granite from Cutting quarry.

Feldspars	65.67
Quartz	23.04
Biotite	11.29
	100.00

The following analysis was made by Leonard P. Kinnicut, of the Worcester Polytechnic Institute, in 1898, and is given here for reference.

[a] This company went out of existence with the completion of its contract for the Pennsylvania Railroad terminal station in New York, and on January 1, 1907, all the quarries here reported as operated by this company passed into the hands of Ralph A. Stewart, Sears Building, Boston, as receiver, and became idle pending the issue of complex litigation.

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Analysis of granite from the Cutting quarry, Milford, Mass.

SiO_2 (silica)	77.08
Al_2O_3 (alumina)	12.54
FeO (iron oxide)	.95
CaO (lime)	.75
MgO (magnesia)	.01
K_2O (potash)	4.99
Na_2O (soda)	3.64
	99.96

Mr. E. C. Sullivan, chemist, of the United States Geological Survey, extracted 0.06 per cent of CaO (lime) from this granite by hot dilute acetic acid. This indicates the presence of 0.107 per cent of $CaCO_3$ (lime carbonate) or calcite, the presence of which mineral is shown in thin sections.

Two tests made at the United States arsenal at Watertown, Mass., in 1898, give it an ultimate strength of 25,252 and 27,226 pounds per square inch. The quarry, opened before 1889, measures about 500 feet north-northwest to south-southeast by 150 feet east-west, and from 20 to 50 feet deep.

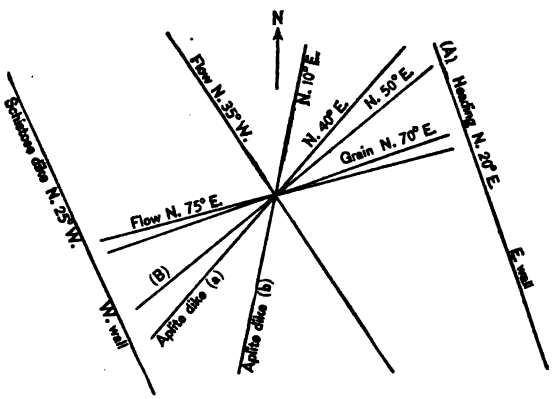

FIG. 7.—Structure at Cutting quarry, Milford, Mass.

The sheets are from 6 inches to 18 feet thick and are horizontal but irregular in places. The rift is reported as horizontal, and the grain as vertical. The peculiar mica diorite schist dike on the west side is described on page 59. Aplite dikes are 5 inches to 2 feet thick. The courses of joints, flow structure, dikes, and grain are shown in fig. 7.

Heading A dips 70° east, and joint B, occurring only at the north end, dips 65° south-southeast. Bands of more biotitic granite with groups of black elliptical schistose knots or inclusions indicate the direction of flow. In thin section these show particles all under 0.1 inch, mostly biotite, next a plagioclase much altered to epidote and zoisite, and lastly quartz. Garnets in roundish grains are also present. Rusty discoloration along the sheets is from 6 to 12 inches thick.

The plant at the quarry consists of 5 derricks, 5 hoisting engines, 3 steam drills, 4 steam pumps, and 1 locomotive; at the cutting shed there are 2 compressors (capacity 1,300 and 290 cubic feet of air per

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minute), 12 surfacers, 30 air plug drills, 113 air hand drills, 2 vertical polishers, 1 polishing lathe for columns of indefinite length and 40 inches diameter, 1 revolving saw for dentals, 7 derricks, 5 hoisting engines, and a 20-ton overhead crane.

Transportation is effected by a siding from the New York, New Haven and Hartford Railroad and a track from quarry to cutting shed.

The product is used mainly for buildings. Specimen structures are the bank building, Newton, Mass.; the Washington-Georgetown street railway depot at Georgetown, D. C.; the New York State monument on Lookout Mountain, Chattanooga, Tenn., which consists of a shaft 6 feet in diameter and 50 feet high made in sections. This quarry furnished part of the base and all the lantern for the Pennsylvania Railroad terminal station at New York.

Eighty-four 31-foot sectional granite columns for the Pennsylvania Railroad station at New York were finished at the cutting shed of this quarry, but the granite blocks for them came from the other Milford quarries operated by this company. Each column is made in four or five sections the blocks for which are first roughly hewn by air plug drills and then centered, attached to an iron pivot at each end, and put in short improvised lathes. After cutting a narrow circular edge by hand on each side two or more sides are first made flat by surfacers, and the sectional column is revolved on its pivot by hand and bars while the rest of the work is done by surfacers. In making the dentals sets of circular steel saws with rectangular teeth are used in connection with chilled iron shot to make vertical incisions in the granite block at the required intervals, and the rest is done by hand.

The East quarry is in Milford Township, 1¾ miles northeast of Milford (fig. 6). Operator in 1906: Milford Stone Company, Milford, Mass.[a]

The granite (specimens D, XXVIII, 14, d, e, g, h) is a biotite granite of light pinkish gray color with more or less conspicuous black spots. The general color is more pinkish than that of the Cutting quarry. Its texture is somewhat gneissoid, medium to coarse. Feldspar and mica measure up to 0.5 inch but the feldspar individuals merge into lenses an inch long, as do also the quartz and biotite. The length and width of the biotite spots in any surface depends upon whether that surface is parallel to the plane of the flow structure or to its side, or crosses it. The quartz areas are always granular, with particles up to 1.75 millimeters across. The rock consists of these minerals in descending order of abundance: A light-pink potash feldspar (microcline and orthoclase) with some intergrown soda-lime feldspar, slightly kaolinized; quartz (with minute cavities arranged in sheets), which in the aggregate has a very pale bluish tinge; a milk-white

[a] See footnote, p. 78.

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to light-greenish striated soda-lime feldspar (albite to oligoclase-albite), partly kaolinized and crowded with minute particles and crystals of epidote and zoisite with a few scales of white mica and rarely calcite; biotite (black mica), some of it chloritized, rarely containing ilmenite, with a rim of leucoxene. The accessory minerals are: Garnet, apatite, magnetite and pyrite (rare), ilmenite, zircon, and allanite (up to 0.6 mm.), rimmed with epidote. The secondary are: Kaolin, a white mica, epidote, zoisite, leucoxene, chlorite, and calcite. The merging of the particles by the gneissoid structure vitiates somewhat the application of the Rosiwal method of estimating the mineral percentages, and the great variation in the amount of biotite on different specimens also affects the results. Four tests on two specimens with meshes 0.5 inch and a total linear length of 28.8 inches yielded these results:

Estimated mineral percentages in Milford, Mass., gneissoid granite from the East quarry.

Feldspar	49.92	58.47	68.22	70.83
Quartz	41.08	35.08	26.92	24.45
Biotite	9.00	6.45	4.86	4.72
	100.00	100.00	100.00	100.00

The following analysis of this granite, made for the company by Prof. R. H. Richards at the Massachusetts Institute of Technology, is given here for reference:

Analysis of Milford, Mass., granite from the East quarry.

SiO_2 (silica)	72.02
Al_2O_3 (alumina)	14.43
FeO (iron oxide)	.89
Fe_2O_3 (iron sesquioxide)	1.25
MnO (manganous oxide)	.33
CaO (lime)	1.18
MgO (magnesia)	Trace.
K_2O (potash)	5.41
Na_2O (soda)	5.85
Loss in ignition	.35

The durability of the polished face on outdoor exposure will vary according to the size and number of the biotite particles.

The quarry is about 100 feet from north to south, by 300 feet from east to west, and from 40 to 80 feet deep.

The chief structural feature is a vertical granite dike 4 feet thick crossing the quarry diagonally. It is a biotite granite, medium to dark greenish to gray in color with pinkish spots. Its texture is fine to medium, with porphyritic feldspars up to 0.6 inch, and exceptionally to 1.3 inches in length. The matrix consists largely of greenish soda-lime feldspar (oligoclase-albite) partly kaolinized and epidotized, a slightly bluish granular quartz, the colors of these two

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minerals giving the rock a general bluish-green tinge, and biotite (black mica). The large pink crystals are potash feldspar (orthoclase with minutely intergrown soda-lime feldspar, also microcline). There is also some potash feldspar in the groundmass. The accessory minerals are: Garnet, apatite (fairly abundant), zircon, and allanite. The secondary minerals are: Kaolin, muscovite, chlorite, epidote, zoisite, and calcite. This dike contains black segregations (inclusions?), mainly of biotite with slightly bluish quartz and epidote. The granite has a flow structure marked by darker bands striking N. 10° W. and dipping 40° E. The granite also contains irregular inclusions, from 1 to 2 feet in diameter, of a dark gray and black banded, very fine grained, somewhat schistose mica diorite (quartz, biotite, and plagioclase, with pyrite, magnetite, and epidote). The rift is reported as horizontal and the grain as vertical. The sheets, from 1 to 15 feet thick, dip 10°–15° SSW. The courses of dike,

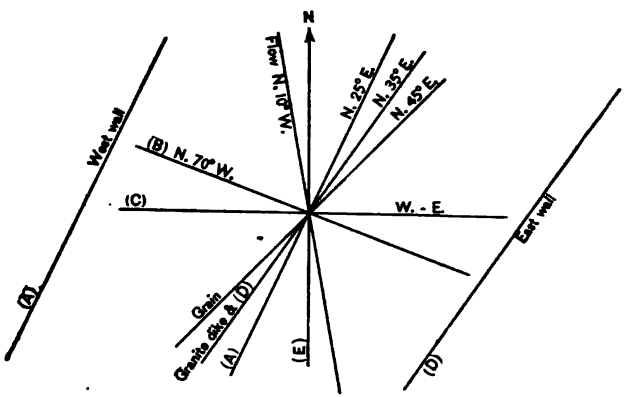

FIG. 8.—Structure at East quarry, Milford, Mass.

flow, grain, and joints are shown in fig. 8. Joints A dip 80° E. and recur at intervals of 100 to 200 feet. Joints B dip 45°–50° SSW., and are spaced 3 feet and over; joints C dip 45° N.; joint D, one only, dips 60° NW.; joints E dip 45° W. The face of joints A on the west wall is coated with a mass of minutely brecciated granite 1¼ inches thick, cemented with calcite, chlorite, fibrous muscovite, and limonite. Joints E are slickensided horizontally. Ferruginous discoloration occurs along the sheets from 6 inches to 2 feet thick.

The plant consists of 10 derricks and 10 hoisting engines, a locomotive crane, a locomotive, an air compressor (capacity 1,900 cubic feet of air per minute), 16 surfacers, 8 large air rock drills, 40 air plug drills, 30 air hand tools, 2 saws for 13-foot granite blocks, a revolving saw for dentals, 2 polishing lathes for columns 25 by 4 feet, 5 vertical polishers, and 2 steam pumps.

Transportation is effected by a siding from the Boston and Albany Railroad.

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The product is used for buildings and monuments. Specimen structures: Hanover National Bank, New York; the entire Boston Public Library, and the Public Library, Columbus, Ohio. In 1906 this quarry was furnishing part of the stone for the basement of the new National Museum at Washington, and also part of that for the Pennsylvania Railroad terminal at New York. Pl. VII, *B*, shows the storage yard of the blocks for this structure from this and other Milford quarries, and illustrates the mode of handling large contracts.

The Norcross quarry is in Milford township, nearly 2 miles northeast of Milford and about one-fourth mile east of the East quarry. (See fig. 6.) Operator, Milford Stone Company.[a]

The granite (specimen D, XXVIII, 15, a) is a biotite granite of light pinkish-gray color with more or less conspicuous black spots. The general color is like that of the East quarry described on page 80, but is marked by light blood-reddish stains not over 0.25 inch across and an inch or two apart. Its texture is like that of the East quarry. The quartz grains measure up to 1.1 millimeters. Its constituents are also the same, but with the addition of red hematitic stains, which originate presumably in the oxidation of magnetite particles.

The quarry measures 175 feet from northeast to southwest, by 100 feet from northwest to southeast, and about 70 feet in depth.

The sheets, which are up to about 15 feet thick, have a low northerly dip. Joints, striking about northeast and dipping over 50° northwest, form the northwest and southeast walls. Another set with a similar strike dips 30°–45° SE., and is spaced 3 to 10 feet. A third set strikes about north or diagonally to quarry, and appears on the southwest wall. The rift is reported as better than at some of the other Milford quarries. Rusty stain, measuring up to 2 feet, appears on the east side of the quarry.

The plant consists of 9 derricks, 6 hoisting engines, a locomotive crane, an overhead electric crane (capacity, 25 tons), an air compressor (capacity, 550 cubic feet of air per minute), a large air drill, 15 air plug drills, 40 air hand tools, 3 surfacers, a circular saw for dentals, 3 polishing lathes (2 for stones 20 by 2½ feet, 1 for stones 30 by 4 feet), 4 vertical polishers, a steam pump, and a stone crusher with a capacity of 80 tons in ten hours.

The West quarry is in Milford township, 1¾ miles north-northeast of Milford. Operator in 1906, Milford Stone Company, Milford, Mass.[a]

The granite (specimens D, XXVIII, 16, a, b) is a biotite granite of light pinkish gray color, like that of the Cutting quarry (p. 78), but with more conspicuous greenish feldspars and much smaller black mica spots. Its texture is medium to coarse, and is even-grained, with very little if any gneissoid structure. The feldspars measure up to 0.5 inch, the black mica to 0.3, rarely 0.4, and the

[a] See footnote, p. 78.

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quartz is granular. Its constituents, in descending order of abundance, are: A delicate pink potash feldspar (orthoclase and microcline, both inclosing large particles of soda-lime feldspar); quartz with some cavities in sheets, clear not bluish; a milk-white to light-greenish soda-lime feldspar (albite to oligoclase-albite), partly kaolinized and epidotized, also with some white mica and calcite; biotite (black mica), some of it chloritized. The accessory minerals are: Garnet, magnetite, pyrite; the secondary: Kaolin, a white mica, epidote, zoisite, and calcite.

A partial analysis, leaving out potash and soda, made for the company by Prof. R. H. Richards, of the Massachusetts Institute of Technology, is given here for reference:

Partial analysis of Milford, Mass., granite from West quarry.

SiO_2 (silica)	75.77
Al_2O_3 (alumina)	13.59
FeO (iron oxide)	.52
Fe_2O_3 (iron sesquioxide)	1.14
MnO (manganese oxide)	.24
CaO (lime)	.94
MgO (magnesia)	Trace.
Loss on ignition	.49
	92.69

The quarry, opened about 1887, measures about 300 feet by 175 feet and is 40 feet in depth.

There are on the east side conspicuous vertical dikes of medium-gray, fine-grained quartz monzonite, from 0.5 inch to 2 feet thick, striking N. 20° W., which occur at intervals of 20 to 100 feet. This consists of clear potash feldspar and cloudy light-gray soda-lime feldspar in almost equal amounts, the latter kaolinized, micacized, and altered to epidote and zoisite; quartz, with hairlike crystals of rutile and cavities; biotite, some of it altered to chlorite. Acessory minerals: Garnet, etc. Secondary minerals: Kaolin, a white mica, epidote, zoisite, chlorite, and calcite. There are two schist dikes already described on page 59. One on the north wall, 2 feet thick, strikes N. 65°–70° W., and dips 65° north-northeast; another, farther south, 20 inches thick, strikes about northwest and is vertical. The sheets, from 2 to 15 feet thick, are nearly horizontal at the north end of the quarry, but dip 15°–20° at the south end. The sheets become irregular at the bottom. Vertical joints strike N. to N. 10° E., are spaced 10 to 100 feet, and form a heading on west side. One at the north end strikes N. 60° W. and dips curving 45°–50° southwest.

The plant consists of 6 derricks, 6 hoisting engines, a locomotive crane, a 50-horsepower engine, an air compressor (capacity, 900 cubic feet of air per minute), 5 surfacers, 8 air plug drills, 12 air hand tools, a saw for 14-foot blocks, and 2 steam pumps.

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Transportation is effected by a half-mile track to the New York, New Haven, and Hartford Railroad.

This quarry furnished the stone for the Bowenville station, at Fall River, Mass.; the John Hancock Insurance Company building, on Federal street, Boston; the Rhode Island Hospital Trust building, on Westminster street, Providence; the Twelfth street station of the Illinois Central Railroad at Chicago, and the base and die of the McKinley monument at Toledo, Ohio. In 1906 it was supplying part of the stone for the Pennsylvania Railroad terminal at New York and the basement of the National Museum at Washington.

This quarry is regarded as nearly worked out, owing to imperfect sheet structure at the bottom.

The Massachusetts Pink quarry is in Milford township, 2½ miles north of Milford, at the north end of a low north-south ridge. (See fig. 6.) Operator, the Massachusetts Pink Granite Company, Milford, Mass.

The granite (specimen D, XXVIII, 21, b) is a biotite granite of light-gray shade with a very slight pinkish tinge and conspicuous black spots. Its texture is somewhat gneissoid, medium to coarse, in other respects and in mineral composition closely resembling the stone of the Cutting quarry, described on page 78.

The quarry, opened in 1902, is 300 feet from east to west by 200 feet across and from 10 to 35 feet deep.

A schist dike 2 feet thick on the west side, striking N. 3° W. and dipping 55° E., has already been mentioned on page 59. The sheets, from 4 to 25 feet thick, dip low east. There are 3 sets of joints: Set A strikes N. 35° W., dips 65° E., and is spaced 100 feet; set B strikes N. 55°–60° E., dips 90°, and is spaced 30 feet; set C strikes N. 55° W. and dips 40° W. The rift is reported as horizontal, and the grain as vertical from east to west. Rusty discoloration is up to 3 inches thick on the lower sheets.

The plant consists, at the quarry, of 3 derricks, 3 hoisting engines, 2 steam drills, an air compressor (capacity, 130 cubic feet of air per minute), 4 air plug drills, a saw for stones 12 feet long, and 2 steam pumps. At the cutting shed there are 1 derrick, 1 hoisting engine, a locomotive crane, an air compressor (capacity, 314 cubic feet of air per minute), 4 surfacers, and 20 air hand tools.

Transportation is effected by a cartage of 3 miles to cutting shed at New York, New Haven and Hartford Railroad track.

The product is used for buildings, bridges, and mausoleums. Specimens: Bridge over Bronx River in Bronx Park, New York; Rochester Safe Deposit and Trust Company building, Rochester, N. Y.; Bloomingdale mausoleum in Greenwood Cemetery, N. Y. In 1906 this company was executing a contract for the McKinley national memorial at Canton, Ohio.

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The Hopkinton quarry is in Hopkinton, Middlesex County, Mass., a mile south of Hayden Row and about 3¾ miles north-northeast of Milford. Operator, the Massachusetts Pink Granite Company, Milford, Mass. This is a small opening near the company's cutting shed, not worked in 1906.

The granite (specimen D, XXVIII, 22, a) is a biotite granite of medium slightly pinkish gray color with fine black specks. Its texture is even-grained, medium, with feldspars generally up to 0.4 inch and mica to 0.2 inch. It is thus pinker and finer grained than that of the Massachusetts Pink quarry. Its constituent minerals, in descending order of abundance, are: A pinkish potash feldspar (orthoclase and microcline), inclosing particles of soda-lime feldspar and slightly kaolinized; faint rose-colored granular quartz in particles up to 1.37 millimeters; a grayish or greenish-gray soda-lime feldspar (albite to oligoclase-albite), a little kaolinized and epidotized with some white mica; biotite (black mica), some of it chloritized. Accessory minerals are: Garnet, magnetite, apatite, zircon, and allanite (bordered with epidote). Secondary minerals: Kaolin, epidote, zoisite, chlorite, and a white mica.

The quarry is 50 feet square and 25 feet deep.

The Bishop mausoleum in Sleepy Hollow Cemetery, at Tarrytown, N. Y., is made of this stone.

The Maguire quarry[a] is in Hopkinton, one-half mile west of Echo Lake and 3¾ miles N. 5° W. of Milford. (See fig. 6.) Operator, Norcross Milford Pink Granite Company, Milford, Mass.

The granite is a biotite granite of light-gray shade with a very slight pinkish tinge and conspicuous black spots. In texture and constituents it is reported as corresponding to the stone of the Cutting quarry described on page 78.

The quarry, opened in November, 1906, measures 300 by 100 feet and up to 15 feet in depth.

The sheets are reported as dipping about 20° northeast.

The plant consists of 2 derricks, 2 hoisting engines, and 2 steam drills.

Transportation involves cartage of 1 mile to the cutting shed on a railroad siding.

In 1906–7 this quarry was engaged in finishing work on the Pennsylvania "terminal concourse" in New York.

The Echo Lake quarry[b] is in Milford township near the Hopkinton line and Echo Lake, 3½ miles N. 5° E. from Milford. (See fig. 6.) Operator, Norcross Milford Pink Granite Company, Milford, Mass.

[a] The data for this quarry were obtained in writing from Mr. F. A. Whipple, the superintendent, as the quarry was opened after the writer's visit to Milford.

[b] The data for this quarry were obtained in writing from Mr. F. A. Whipple, the superintendent, as the quarry was opened after the writer's visit to Milford.

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The granite is a biotite granite of light gray shade, with slight pinkish tinge, reported as a little more pinkish than that of the Cutting quarry described on page 78.

The quarry, opened in October, 1906, measures 60 by 40 feet and up to 20 feet in depth.

The sheets are reported as dipping about 20° west, but as irregular, making this a "bowlder quarry" A "soft heading," that is a schist dike like that at the Cutting quarry, described on page 59, is reported as forming the west side of quarry with a north-northwest strike.

The plant consists of a derrick and hoisting engine and a steam pump.

Transportation involves cartage of 1 mile to the cutting shed which is on a railroad siding.

In 1906–7 the quarry was furnishing material for the completion of the Pennsylvania "terminal concourse" in New York.

The North Milford quarry is in Milford township, 2½ miles about N. 7° W. from Milford and one-third mile southwest of the Massachusetts Pink quarry. (See fig. 6.) Operator, North Milford Granite Company, 116 Purchase street, Milford, Mass.

The granite is a biotite granite of light gray shade with a very slight pinkish tinge and conspicuous black spots. In texture and constituents it is identical with the stone of the Cutting quarry described on page 78.

The quarry, opened in 1905, is 100 feet square and averages 5 feet in depth.

Owing to the irregularity of sheets this is a bowlder quarry. Vertical joints strike N. 80° E. and N. 25° E. The rift is reported as horizontal and the grain as vertical with N. 80° E. course.

The plant consists of 2 small derricks and 2 hoisting engines.

Transportation is by cartage 2½ miles to the New York, New Haven, and Hartford and the Boston and Albany railroads.

The product is used for construction only. Specimen buildings: The granite part of Redmond Bank building, 31 Pine street, and the trimmings for tenements of Homes Suburban Company, One hundred and fifty-sixth street, New York. Contract in 1906: The trimmings for the residence of Hennen Jennings, northeast corner of Massachusetts avenue and Sheridan Circle, Washington, D. C.

The Carroll quarry is in Milford township, 1¾ miles north of Milford and one-half mile north-northwest of Cedar Swamp pond. (See fig. 6.) Operator, Webb Pink Granite Company, office, 40 Crescent street, Worcester, Mass.

The granite (specimen D, XXVIII, 18, b) is a biotite granite of light-gray shade with conspicuous black spots. This is the whitest of the Milford granites. Its texture is somewhat gneissoid medium to

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coarse, with feldspars and mica up to 0.5 inch across and with finely granular quartz. Its constituents, in descending order of abundance, are: A cream-colored to palest pink potash feldspar (orthoclase and microcline), with minutely intergrown soda-lime feldspar and slightly kaolinized; clear, not bluish, quartz in grains up to 0.5 mmillimeter, and with cavities some of which are in sheets; clear to cloudy, some very pale greenish, soda-lime feldspar (albite to oligoclase-albite), not a little kaolinized and epidotized; biotite (black mica), some of it chloritized. Accessory minerals are: Garnets (minute and usually in rows), apatite, fluorite, allanite (rimmed with epidote), and zircon. Magnetite and pyrite not observed. Secondary minerals are: Kaolin, epidote, zoisite, chlorite, calcite, white mica.

The following analysis of this granite, made for the company by Robert C. Sweetzer, of the Worcester Polytechnic Institute, in 1905 is given here for reference:

Analysis of Milford, Mass., granite from the Carroll quarry.

SiO_2 (silica)	76.52
A_2lO_3 (alumina)	12.21
FeO (iron oxide)	2.66
CaO (lime)	.79
MgO (magnesia)	.13
K_2O (potash)	4.68
Na_2O (soda)	2.86
H_2O (water)	.41
	100.26

Specific gravity 2.633.

The quarry, opened in 1905, measures about 500 by 200 feet and up to 30 feet in depth.

The sheets, from 6 inches to 15 feet thick, undulate horizontally. The rift is reported as horizontal and the grain as vertical, with N. 65° E. course. Joints A strike N. 60° W., dip 90° and are spaced 10 to 60 feet. Joints B strike N. 20° E., dip 90°, and form headings at the northwest and southeast sides and in the middle. Joints C strike N. 80° W. and dip 45° south, of which one is in the middle and another 25 feet east of it. There is a quartz vein up to 0.1 inch wide, with a N. 10° E. course. Rusty discoloration is 2 inches thick on sheet surfaces.

The plant, which includes that of Webb quarry No. 8 and the cutting machinery for the product of both, consists of 8 derricks, 6 hoisting engines, 6 locomotive cranes, 2 overhead cranes (capacity 20 tons each), 2 air compressors (capacity, 1,200 and 1,800 cubic feet of air per minute), 2 large air drills, 55 air plug drills, 84 air hand tools, 8 surfacers, and an air-driven pump. There is also a 200 kilowatt direct-current generator for operating the railroad and cranes.

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Specimen structures: The Commercial National Bank, Chicago, and the John Hancock Building No. 2, in Boston, were built partly of stone from this quarry and partly from that of Webb quarry No. 8.

The Webb quarry No. 2 is in Milford township, 2 miles north of Milford. (See fig. 6.) Operator, Webb Pink Granite Company, office, 40 Crescent street, Worcester, Mass.

The granite (specimens D, XXVIII, 17, a, b) is a biotite granite of medium pinkish and greenish-gray color with black spots which are not as conspicuous as those of the Carroll or Cutting quarry stone. Its texture is even-grained, medium, with feldspars up to 0.4 and mica up to 0.2 inch in diameter, and finely granular quartz. Its constituents, arranged in descending order of abundance, are: A delicate pink potash feldspar (orthoclase and microcline), minutely intergrown with soda-lime feldspar and with quartz and more or less kaolinized; a very faintly bluish and finely granular quartz with cavities some of which are in sheets; a yellow greenish to clear soda-lime feldspar (albite to oligoclase-albite), generally kaolinized and epidotized also with some scales of white mica and chlorite; biotite (black mica). Accessory minerals are: Magnetite, apatite, and zircon. Secondary minerals are: Kaolin, epidote, zoisite, chlorite, and a white mica. Calcite not observed.

An estimate of the mineral percentages by the Rosiwal method with half-inch mesh and total linear length of 46.5 inches yields these results:

Estimated mineral percentages in Milford, Mass., granite from Webb quarry No. 8.

Feldspar	55.91
Quartz	35.66
Biotite	8.43
	100.00

Mr. W. T. Schaller, chemist, of the United States Geological Survey, extracted from an average specimen of this granite, by means of hot dilute acetic acid, 0.04 per cent of CaO (lime), which indicates the presence of 0.07 per cent of $CaCO_3$ (lime carbonate), or calcite. This lime is, of course, irrespective of that combined with silica in the oligoclase feldspar and epidote.

The stone takes a fair polish, but the mica particles are sufficiently large to detract from the durability of the polish in prolonged outdoor exposure.

The quarry, opened in 1905, measures about 250 by 200 feet and up to 30 feet in depth.

A flow structure, shown by biotitic streaks, strikes N. 40° W., and dips 50° northeast. The sheets, from 5 to 12 feet thick, are horizontal in irregular undulations. Joints A strike N. 40° W., dip 90°, and are

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spaced 3 to 10 feet. Joints B strike N. 15° E., dip 75° E., and recur at an interval of 8 and one of 50 feet. The rift is reported as horizontal, and the grain as vertical with an east-west course.

The description of the plant connected with this quarry, of the plant of the Carroll quarry, and of the cutting shed for both was given under Carroll quarry on page 88.

Transportation from both of these quarries is effected by tracks to sidings of the New York, New Haven and Hartford Railroad. These tracks are 3,750 feet long.

Specimen structures: Pedestal of General Devens statue at Worcester, Mass. In 1906 the company was filling a contract for the power service plant of the Pennsylvania Railroad in New York with stone from this and the Carroll quarry.

The Webb Pink Granite Company, besides the two quarries described, has several other openings or prospects on the same property.

QUINCY.

Topography.—There is a conspicuous range of low hills south of Boston, known as the Blue Hills, which curves from a point (Great Blue Hill) 11 miles south-southwest of the city to a point (Forbes Hill) 7½ miles south-southeast of it, and whose tops lie between the 180 and 640 foot levels. See Boston and Dedham topographic sheets of the United States Geological Survey. The Quincy granite district lies at about the northeastern end of this range, in the townships of Quincy and Milton of Norfolk County. Some of the quarries are on the North Commons from about one-half mile west-southwest to a mile west of Quincy Center, others are in West Quincy from 1½ to 2 miles about west-southwest of the Center, and 2 are in Milton some 3 miles west of the Center. Quarry locations are shown on the map, Pl. II. The reader will find some interesting historical matter on the Quincy quarries in a chapter on the early history of the granite industry in New England by George P. Merrill.[a]

General geology.—The geology of the vicinity of Quincy and Boston is very complex and difficult, and has long been under investigation and discussion by several resident and other geologists.[b] As the results of these investigations have not yet been published in final form the following outline of the salient geological features must be regarded as only provisional. The granite of Quincy was part of a great deeply buried mass of molten granitic material of various

[a] Rept. Smithsonian Institution, 1885–6, pt. 2, pp. 285–288.

[b] Crosby, W. O., Genetic and structural relations of the igneous rocks of the Lower Neponset Valley: Mass. Am. Geol., July-August, 1905, pp. 39–41; Emerson and Perry, The green schists and associated granites and porphyries of Rhode Island: Bull. U. S. Geol. Survey No. 311, 1907, Quincy granitic group, p. 51; Professor Crosby's forthcoming Part IV, Boston Basin Series (Bost. Soc. Nat. Hist.), will contain Prof. Florence Bascom's complete work on both the volcanics and plutonics of the Boston basin; Mansfield, G. R., The origin and structure of the Roxbury conglomerate: Bull. Mus. Comp. Zool. Harvard Coll. (Geol. Ser., VIII, 4) vol. 49, 1906. General summary, pp. 259, 260, also p. 161, map, pl. 7, section pl. 6.

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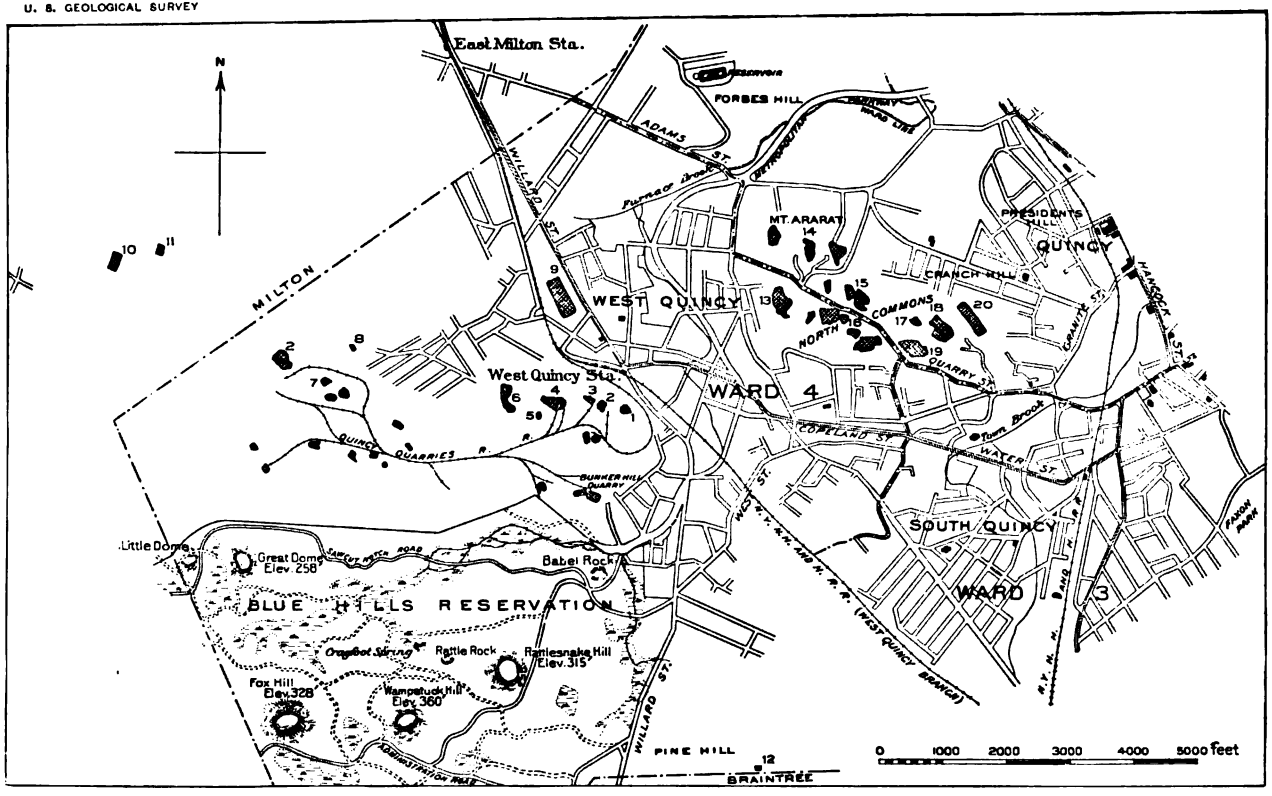

MAP SHOWING LOCATIONS OF QUINCY GRANITE QUARRIES.

1. Wigwam quarry, Badger Brothers.
2. Reinhalter quarry, Thomas F. Mannex.
3. Swingle quarry, J. S. Swingle.
4. Granite Railway quarry Granite Railway Company.
5. Lepage quarry, Lepage Granite Quarry Company.
6. John Cashman quarry.
7. Gold-leaf quarry, Quincy Quarries Company.
8. Savo Granite Company's quarry.
9. Rogers quarry, Quincy Quarries Company.
10. Maguire & O'Heron quarry, Milton
11. Mount Pleasant quarry, Mount Pleasant Quarry Company, Milton.
12. Angelo Sartori & Brothers' quarry.
13. Dell Hitchcock quarry, Quincy Quarries Company.
14. Merry Mount quarry, Merry Mount Granite Company.
15. Ballou quarry, John C Ballou.
16. Djerf & Winquist quarry.
17. Sahlsten quarry, Theodore Sahlsten.
18. McKenzie & Pattison quarry
19. Hardwick quarry, C. H. Hardwick & Co.
20. Field & Wild quarry.
21. Fuller quarry, Quincy Quarries Company.

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kinds, which was intruded into a considerable mass of overlying slates, etc., of Cambrian and possibly of later age, which in places were entirely removed by subsequent erosion. That these slates were originally marine clayey sediments is shown by the presence of fossil crustaceans in some of them in the town of Braintree. After a long interval a large part of the region became again submerged during the Carboniferous period, and the advancing sea either deposited a conglomerate or covered a torrential one containing pebbles from the exposed igneous and sedimentary rocks of Cambrian or post-Cambrian time. The granite pebbles of the conglomerate area which adjoins the Blue Hills on the north are not Quincy granite, but contain pink and green feldspars like the granite of Dedham and Randolph.[a]

This submergence continued until the conglomerate was overlaid by a considerable accumulation of clayey sediments. During the post-Carboniferous crustal movement, which affected a large part of the continent, these clays became slate and were powerfully folded; basic dikes were also intruded into the granite and the overlying beds. The corrugation and elevation of the surface in post-Carboniferous time exposed the Carboniferous beds to erosion, so that portions of the granite surface which had been covered by them again became exposed. In Triassic time more basic dikes forced their way through fissures in the granite. Events in this region were further complicated by the occurrence of eruptions of very siliceous rocks at various points and times. It should also be borne in mind that although the granitic material was intruded into what appear to be Cambrian beds, there is some uncertainty as to when, between Cambrian and Carboniferous time, the intrusion took place. In this connection attention might be directed to the possibility that a granitic intrusion in Cambrian rocks may point to more than a local crustal movement toward the close of Cambrian time.[b]

Description of Quincy granite.—The following epitomizes the writer's descriptions of rough and polished specimens and thin sections of granite from all the quarries as given farther on. The more recent scientific accounts of this granite are by Wadsworth, Merrill, White, and Washington.[c]

Quincy granite is a riebeckite-ægirite granite, riebeckite and ægirite being varieties of hornblende and augite, respectively, both rich in

[a] See Mansfield, op. cit.

[b] See Dale, T. N., The geology of the north end of the Taconic range: Am. Jour. Sci. (4), vol. 17, p. 185, 1904; also Geology of Hudson Valley between the Hoosic and the Kinderhook: Bull. U. S. Geol. Survey No. 242, 1904, pp. 47, 53, 55.

[c] Wadsworth, M. E., Notes on the petrography of Quincy and Rockport: Proc. Bost. Soc. Nat. Hist., vol. 19, 1881, pp. 309–316; Merrill, G. P., The collection of building and ornamental stones in the United States National Museum: Rept. Smithsonian Institution, 1885–6, pt. 2, pp. 409, 418; White, T. G., A contribution to the petrography of the Boston Basin: Proc. Bost. Soc. Nat. Hist., vol. 28, 1897, pp. 128–132; Washington, H. S., Sölvsbergite and tinguaite from Essex County: Mass. Am. Jour. Sci. (4), vol. 6, 1898, p. 181.

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soda (8 to 10 per cent) and in iron sesquioxide (about 28 per cent) but poor in alumina, magnesia, and lime. The general color of the fresh normal granite ranges from a medium gray or bluish or greenish or purplish gray to a very dark bluish gray, all with black spots which, on closer inspection, are blue-black or green-black or a mixture of both.

Its texture is medium to coarse and even grained, with feldspars up to 0.4 and 0.5 inch, and the black silicates up to 0.3 and 0.4 inch.

Its constituents, in descending order of abundance, are: (1) A medium to dark bluish or greenish-bluish gray feldspar (orthoclase, much of it twinned) always with minutely intergrown soda-lime feldspar (albite to oligoclase-albite). It is apparently more or less darkened by a varying number of extremely minute particles of a black mineral, which are not absolutely distinguishable from opaque particles of kaolin, and is always slightly epidotized by minute particles of grass-green epidote, and whitened by partial kaolinization or black streaked by clusters of radiating fibrous crystals of dark brown hornblende. The fresh feldspar always contains crystals of blue-brownish riebeckite from 0.01 to 1.0 millimeter long by up to 0.01 millimeter in width. These crystals, and also the epidote, are in many specimens arranged in two rectangular directions, one that of the twinning plane, the other that of the intergrown soda-lime feldspar. In some sections (p. 107) the feldspars were found crossed by rift and grain cracks filled or overlain by minute crystals of riebeckite, thus evidently of secondary origin like those on joint planes described on page 60. (2) Medium to dark smoky quartz, some of it with a slight bluish tinge. It contains cavities (many with liquid and movable vacuoles) arranged in streaks and sheets and measuring from 0.0028 to 0.02 millimeter in length. This quartz also incloses minute black particles, and in places hairlike crystals, presumably of rutile, more rarely minute crystals of riebeckite, one measuring 0.178 by 0.0047 millimeter. (3) A little lime-soda feldspar (albite to oligoclase-albite). (4) Riebeckite (blue-black in hand specimen, but Prussian blue and brownish gray in thin section) and ægirite (green-black in hand specimen, but light green to emerald green in thin section), both minerals being in many specimens intergrown. The ægirite may surround riebeckite or these relations may be reversed. In some specimens riebeckite in slender crystals appears like a secondary growth on ægirite. The ægirite in others appears as filling spaces between the other minerals. Basal sections of it appear as if corroded. All of the riebeckite can not be secondary, because it appears in minute crystals within the quartz and forms the center of large crystals of ægirite. Nor can all the ægirite be secondary, because crystals of it also occur within quartz particles and also surrounded by radiating

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crystals of riebeckite. (See page 110.[a]) The ægirite is apt to contain particles of magnetite and carbonate.

The accessory minerals are: Ilmenite, magnetite (probably), pyrite (very rare), zircon in doubly terminated crystals, fluorite, titanite, and the minute black particles in quartz. The secondary minerals are: Kaolin, epidote, yellow-brown to orange hornblende in fibrous crystals, chlorite, calcite, leucoxene, hematite, limonite (associated with zircon and ægirite), and part of the riebeckite. One of the altered granites (Sartori quarry) contains spherulites which polarize like zircon.

Estimates of the mineral percentages by the Rosiwal method yield the following figures for the "medium," "dark," and "extra dark:"

Estimated mineral percentages in Quincy granite, extremes and averages.

	Average.
Feldspars, 55.80 to 69.51	60.02
Quartz, 22.06 to 33.74	30.60
Riebeckite and ægirite, 7.47 to 11.10	9.37

Of course the microscopic particles of the soda-iron silicates are not included in these figures.

The following analysis of Quincy granite was published by Henry S. Washington in 1898:[b]

Analysis of riebeckite-ægirite granite from the Hardwick quarry, Quincy, Mass.

SiO_2 (silica)	73.93
TiO_2 (titanium dioxide)	.18
Al_2O_3 (alumina)	12.29
Fe_2O_3 (iron sesquioxide)	2.91
FeO (iron oxide)	1.55
MnO (manganese oxide)	Trace.
MgO (magnesia)	.04
CaO (lime)	.31
Na_2O (soda)	4.66
K_2O (potash)	4.63
H_2O (water above 110°)	.41
	100.91

Specific gravity 2.642 at 22° C.

Messrs. E. C. Sullivan and G. Steiger, chemists, of the United States Geological Survey, extracted by means of hot dilute acetic acid per-

[a] For analyses and optical features of riebeckite and ægirite see Rosenbusch, H., Mikroskopische Physiog. d. Min. u. Gesteine, 4th ed., 1905, vol. 1, pt. 2, pp. 213, 244; for discussion as to their origin see Murgoci, G. M., On the genesis of riebeckite and riebeckite rocks: Am. Jour. Sci. (4) vol. 20, 1905, pp. 133-145; and Cross, W., on some secondary minerals of the amphibole and pyroxene group: Am. Jour. Sci. (3), vol. 39, 1890, pp. 359-370. Murgoci (op. cit., p. 138) sums up the views on the origin of these two minerals thus: "Some petrologists have considered the ægirite as a transformation product of riebeckite, and others have taken the riebeckite for a secondary product of ægirite. Most petrologists state, however, that riebeckite and ægirite are primary in their rocks." On the next page in a footnote he adds: "The best argument for the primary existence of the ægirite is its occurrence in the same rock, with little thin needles of riebeckite, which could not resist even the slowest and slightest action of transformation."

[b] See Am. Jour. Sci., 4th ser., vol. 6, 1898, p. 181; also Jour. Geol., vol. 6, 1898, p. 793.

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centages ranging from 0.11 to 0.28 per cent of CaO (lime) from specimens from four quarries in Quincy and Milton. This lime indicates the presence of from 0.196 to 0.50 per cent of $CaCO_3$ (lime carbonate) or calcite.

Quincy granite for monumental purposes goes under the names of "medium," "dark," and "extra dark." The estimated mineral percentages show that these differences in shade are due in part to a variation in the amounts of the black silicates and of the smoky quartz. In part they are also due to a variation in the degree of kaolinization of the feldspars and in the abundance of black particles and of hornblende in them. The smokiness of the quartz appears to be due to infinitesimal particles of some black mineral. The bluish tint of the feldspars is due to microscopic crystals of riebeckite and its greenish hue to minute epidotes. The contrast of shade is chiefly between the black silicates and the combined quartz and feldspar except where the feldspar is whitened by kaolinization, which causes it to stand out from the quartz. "Light Quincy granite," which is of medium-gray shade, is considered second grade and sells for rock face and hammered work.

Quincy granite is noted for its high polish, which comes out strikingly on columns and balls, as shown in Pl. IV. This susceptibility to high polish is due to the absence of mica and to the coarser cleavage of the varieties of hornblende and augite which take its place. The imperfections which occur in the polish of some blocks are due to particles of ægirite partially altered before quarrying. (See p. 55.)

A peculiar variety of Quincy granite, known as "Gold leaf," described on page 115, is the lightest monumental stone quarried there. Its general color is medium bluish-green gray, speckled with black and light yellow brown. The quartz, clear to light smoky, is finely granular, like that of Milford, Mass., and sparkles on the polished face. Wherever the yellow spots, which are caused by limonite stain, coincide with the granular quartz, they are more conspicuous. In other respects its constituents are identical with those of the riebeckite-ægirite granite of Quincy. A minor variety is that of the Ballou quarry, which has sparsely disseminated minute cherry-red dots, probably from the oxidation of magnetite particles.

Other and cheaper varieties of Quincy granite are suitable only for building purposes. Such are the "extra light" (pea-green), the pink, and the greenish brown, described on pages 112, 114, 120. The "orei" (hematitic) finds its way to the dumps. These various colors are due to changes in the feldspars or ægirite, brought about by underground alterations which have been long in process. (See further p. 55.) The yellow, rusty discoloration (sap) referred to on page 35 is of still later date, affecting the stone for a few inches only along the sheet and joint surfaces.

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Geology of Quincy quarries.—The cylindrical pegmatite dike with large ægirite crystals at the Ballou quarry, first studied by Prof. C. Palache, has already been described on page 49. Quartz veins up to an inch thick, probably of pegmatitic origin, and giving rise to subjoints and zones of lighter color, occur at several quarries and are described on page 48 and illustrated in Pl. III, *B*. Some of these veins contain ilmenite and a carbonate besides a little fluorite. Some minute ones (0.04 to 0.1 inch wide) are also apt to contain fluorite and calcite.

At the Granite Railway quarry in West Quincy there is a 15-foot diabase dike striking about N. 75° W. in which the feldspar is altered to a white mica. It has a greenish rim, in which the augite is all chloritized. At the Merry Mount quarry on the North Commons a 5-foot dike, striking about north, appears to be a garnetiferous biotite lamprophyre. At the Djerf & Winquist quarry, near the last, two basic dikes strike about east, and another occurs near the Dell Hitchcock quarry, but these were not microscopically studied.

The segregations (knots) are of three kinds: (1) Very fine-grained aplitic, dark bluish gray with a matrix of potash feldspar, quartz, and more or less soda-lime feldspar (albite to oligoclase-albite), with particles from 0.025 to 0.3 millimeter, containing porphyritic crystals of ægirite (with some riebeckite) up to 0.84 by 0.09 millimeter, which appear as if corroded. Zircon, magnetite, orilmenite, and abundant apatite occur as accessories. There are also minute crystals of riebeckite and titanite, with secondary limonite and carbonate. (2) Medium-grained and medium gray, lighter or of same shade as the inclosing granite. These are identical with the granite, but the orthoclase tends to complete its crystals. One such knot contains a complete section of an ægirite crystal in the center of a quartz area many times its size. Another has secondary orange fibrous hornblende growing on ægirite. Zircon and fluorite are accessory. (3) Some muddy yellow to greenish knots consist of potash feldspar (orthoclase) minutely intergrown with soda-lime feldspar, in twins from 0.2 to 1.0 millimeter long, and quartz, with ægirite and riebeckite, which usually appear to fill spaces between the other minerals. The soda-silicates are more or less altered to fibrous muscovite and carbonate; the feldspars are also streaked with white mica and contain secondary epidote. The usual magnetite, apatite, and riebeckite are present.

The dimensions of the large knots given in the quarry descriptions were obtained from the foremen. It is assumed that they are segregations, not inclusions. The sizes range from half an inch to 2 feet by 1 foot 6 inches, 2 feet 6 inches by 2 feet 6 inches, 3 feet by 4 inches, and 6 feet by 2 feet. They are usually small and roundish or elliptical.

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Rift in the Quincy quarries is reported as generally vertical or nearly so with a course from N. 65° W. to due west, and the grain as vertical or nearly so and about north to south. The grain is generally feeble. Rift courses of N., N. 10° E., and N. 30° W. are reported at a few quarries, and at three the grain is reported as horizontal. At the Swingle quarry, which is crossed by a diagonal heading striking north, the rift is reported to be north-south on the west side of that heading but as east-west on its east side. The angle of inclination of both rift and grain is reported as subject to modifications, some of which are probably only local; others are due to general physical principles. At the Reinhalter quarry the rift is vertical below but not quite vertical near the surface. Mr. Cashman states that in his quarry the grain is 90° when the sheet is split from the top, but if split from the side it is steeply inclined. Mr. Galvin reports that the grain is horizontal when the drilling is done from east to west, but dips 20° when it is done from north to south. The degree of dip of rift and grain is affected by gravity; that is, it is proportioned to the heft of the block on one side or the other of the fracture. Two foremen find that when the sheets are inclined the dip of the rift swerves from the vertical. At the Field & Wild quarry rift and grain are reported as varying greatly in different blocks. The subject of rift will be found more fully discussed on page 19, and its apparent relation to the sheets of fluidal cavities is explained on page 42.

The crushing of cores between drill holes made in channeling shows that the Quincy granite mass is now under compressive strains from the north and south and the east and west. This strain in some quarries appears to increase with their depth. At one quarry not only are north-south channels closed by it, but diagonal subjoints are started from the channel.

Sheet structure in Quincy is regular in places, as at the Dell Hitchcock quarry (Pl. III, *A*), where it consists of lenses with an undulating course usually parallel to the rock surface, and increasing in thickness downward. But it is oftener obscure and irregular owing to the shortening and thickening of the lenses, which results in "bowlder quarries." Sheet structure extends to a depth of 150 feet from the rock surface at the Ballou quarry on the North Commons and to a depth of 175 feet in the Reinhalter quarry in West Quincy. The inclination of the sheets is in places as high as 45°, and their thickness ranges from 6 inches to 27 feet. They are rarely intersected by sharp curving joints or partings known as "toe nails." The origin of sheet structure will be found somewhat fully discussed on pages 22, 29. In quarrying it is safe to count on a gradual increase in the thickness of the sheets downward. If for a space thin sheets recur they may be expected to give way to thicker ones below. The quarry adjacent to the Dell Hitchcock is reported to have been

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A. DELL HITCHCOCK GRANITE QUARRY, NORTH COMMONS, QUINCY, MASS., FROM THE WEST SIDE.

Showing lenticular sheets and their increase in thickness downward. Depth, 100 feet.

B. SOUTH SIDE OF GALVIN GRANITE QUARRY, NORTH COMMONS, QUINCY, MASS.

Showing westward-dipping quartz veins crossed by short vertical subjoints.

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abandoned because of the appearance of thin sheets below and the assumption that they would not be succeeded by thicker ones. At the Reinhalter quarry, which in 1906 was 225 feet deep, the lowest mass, already 45 feet thick, had not then been penetrated.

The general character of the jointing can be inferred from the quarry diagrams, figs. 9–12. The principal joint systems are: (A) That striking N. 60° to 85° W. to N. 83° E., and its complementary set (B), N. to N. 20° E.; then a single set (C), striking N. 10° to 30° W., and lastly one (D) striking N. 25° to 55° W., with its complementary set (E) striking N. 45° to 50° W. A noticeable feature in some of the deeper quarries is the vertical discontinuity of the headings. Some of the bottom ones disappear upward within 100 feet of the surface; others again which occur at the surface disappear below. Some of the joints are also intermittent. The possibility of a bad heading dying out below is as encouraging to the quarryman as the possibility of the appearance of a new one below is discouraging. This discontinuity in the joints and headings reflects the complex character of the stresses to which the region was exposed.

The remarkable black joint coatings of riebeckite have been described on page 60. At one of the Milton quarries this appears on the sheet surfaces also, and the adjacent granite is lighter in shade.

From these summaries on the granite and on its geology as exposed at the quarries the following inferences may be drawn: The riebeckite-ægirite granite of Quincy had ægirite as one of its original constituents and riebeckite as another, but some of its riebeckite is clearly secondary, as shown by its occurrence in rift cracks and on sheet and joint faces. The formation of this mineral on these faces indicates that the granite after acquiring its sheet and joint structure was subjected to metamorphism, probably that which accompanied the post-Carboniferous crustal movement. The source of this secondary riebeckite may well have been the ægirite itself. The hematite-spotted granite ("oreï"), the pink granite, and the greenish-brown granite (described on pages 54, 55), while evidently due to the alteration of the ægirite particles to magnetite, hematite, green hornblende, biotite, and chlorite, owe these mineral changes partly to processes of deep-seated alteration and partly to regional metamorphism, and the pea-green variety is due to deep-seated epidotization of its feldspars, which may have involved access of calcareous and ferruginous waters. The latest change was the brownish iron staining along sheet and joint surfaces, which is attributable to percolating surface water oxidizing the magnetite, and soda-iron silicates and possibly also adding fresh supplies of iron sesquioxide obtained from deposits once overlying the granite.

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The Quincy quarries.—The Dell Hitchcock quarry is on the North Commons, south of Quarry street. (See map, Pl. II, No. 13.) Operator, The Quincy Quarries Company, Quincy, Mass.

The granite (specimen, D, XXVIII, 67, d), "dark Quincy," is a riebeckite-ægirite granite of somewhat dark and slightly bluish-gray color with black spots. Its texture is medium to coarse, even grained, with feldspar up to 0.5 inch, and black silicates usually not over 0.3, but occasionally 0.5 inch. Its constituents, in descending order of abundance, are: A medium bluish and greenish gray potash feldspar (orthoclase, usually twinned) minutely intergrown with soda-lime feldspar, and inclosing minute crystals of riebeckite and particles of epidote, and in places somewhat kaolinized; smoky quartz with cavities (some with liquid and vacuoles), and black particles in streaks or sheets; a little separate soda-lime feldspar (albite to oligoclase-albite); ægirite, much of it intergrown with riebeckite. The accessory minerals are: Magnetite, zircon, and fluorite. The secondary: Kaolin, calcite, epidote, and brown fibrous hornblende and chlorite in rift cracks in feldspar.

The contrast in the rough stone is entirely between the black silicates and the combined quartz and feldspar.

A specimen (D, XXVIII, 67, c) of the "light Quincy" is more of a medium gray with a slight greenish tinge. Its general composition is the same as the "dark Quincy" with probably more kaolin and epidote in the feldspars. The contrasts are more marked.

The quarry, opened before 1826, is about 500 feet N. 25° E. by 500 feet N. 65° W. and 100 feet deep. (See Pl. III, *A*.)

The sheets, from 6 inches to 12 feet thick, are lenticular, undulating horizontal. As shown in the plate the upper 30 feet consists of very thin sheets which, owing to their thinness and rustiness, are valueless. Joints A strike N. 70° W., dip 90°, and are spaced irregularly, but never completely cross the quarry. A set with similar strike, but dipping 30°–35° north-northeast, is represented by two or three at the north end, and two on the east wall near the south end. Joints C strike N. 20° W., dip 90°, and are spaced 14 to 30 and 400 feet. At the bottom there are short intermittent joints dipping east and in other directions, which are coated with riebeckite and thus have blue-black surfaces. (See further on p. 60.) The rift is reported as vertical with a N. 65° W. course, and the feeble grain as at right angles to it and vertical. A dark bluish-gray knot (67, e) contains porphyritic crystals of ægirite, as described under group 1 on page 95. There are also some of group 3. The boundaries between the "light" and "dark" granite are not well defined. Rusty discoloration is from 2 to 18 inches thick. Where it is only 2 inches the feldspar is usually slightly greenish for several inches back.

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The plant consists of 3 derricks, 3 hoisting engines, 1 "tag engine," an air compressor (capacity 313 cubic feet of air per minute), 4 steam drills, 11 air-plug drills, and 2 steam pumps.

Transportation involves a cartage of three-fourth mile to railroad, and averages about a mile to local cutting sheds.

Specimen: Three bases and die of the Jefferson monument at Louisville, Ky.

The Merry Mount quarry is on the North Commons, north of Quarry street. (See map, Pl. II, No. 14.) Operator, Merry Mount Granite Company, Quincy, Mass.

The granite (specimen D, XXIX, 86, a), "dark medium Quincy," is a riebeckite-ægirite granite of somewhat dark, slightly purplish gray color. Its shade is slightly darker than that of 67, d. The texture is medium to coarse, even grained, with feldspar up to 0.5 inch and black silicates up to 0.3 inch. Its constituents, in descending order of abundance, are: A medium and dark or slightly greenish-gray potash feldspar (orthoclase, generally twinned), always minutely intergrown with soda-lime feldspar (albite to oligoclase-albite), in places somewhat kaolinized and inclosing riebeckite crystals up to 0.094 by 0.0094 millimeter and particles of epidote, also hematite stain; smoky quartz with streaks or sheets of cavities and minute black particles; a little separate soda-lime feldspar (oligoclase-andesine); blue-black riebeckite and green-black ægirite, either separate or intergrown. The accessory minerals are: Zircon (abundant in crystals up to 0.47 millimeter) and fluorite. Secondary: Kaolin, epidote, limonite, and hematite.

The purplish tinge of this granite is evidently due to hematite in the feldspar. The contrast in the rough stone is entirely between the black silicates and the general gray of the quartz and feldspar.

Mr. E. C. Sullivan, chemist, of the United States Geological Survey, extracted 0.11 per cent of CaO (lime) from this granite by means of hot dilute acetic acid, which indicates the presence of 0.19 per cent of $CaCO_3$ (lime carbonate) calcite. The presence of this mineral is also shown by the microscope.

A specimen of "medium Quincy" (D, XXIX, 86, b) is a trifle lighter in shade and has a slightly greenish tinge. Its texture and constituents are the same, except that the feldspar borders on light-gray, hematite stain is absent, and a particle of pyrite appears. The quartz is darker than much of the feldspar.

The quarry, opened in 1856, measures about 300 feet north to south by 200 across and from 130 to 150 feet in depth.

On the west wall is a 5-foot dike of lamprophyre, described on p. 95, which has a N. 10° E. strike. The sheets are lenticular in all directions and mainly horizontal, ranging from 1 to 16 feet in thickness. They thicken downward, but with thin sheets at intervals, to a depth

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of 40 feet. Joints B strike N. 10° E., dip 90°, or steep west, are spaced 5 to 20 feet, and form a heading near the dike. One diagonal joint (D) strikes N. 50° E. and dips 70° northwest. The rift is reported as striking N. 10° E. and vertically or steeply west, and the grain as east to west, dipping steeply north. In individual blocks the rift is considerably affected by gravity. Knots, both dark and light, are from 1 to 6 inches across, but some are reported as 2 feet 6 inches in two diameters. Rusty discoloration on sheet surfaces is from 1 to 6 inches thick.

The plant consists of 4 derricks, 2 hoisting engines, 2 air compressors (capacity 100 and 250 cubic feet of air per minute), 2 steam drills, 14 air-plug drills, 8 air hand tools, and a steam pump.

Transportation involves cartage of a mile to railroad or cutting shed.

The product consists chiefly of the "dark medium." Specimen: The Barney mausoleum at Springfield, Mass.

The Ballou quarry is on the North Commons, north of Quarry street. (See map, Pl. II, No. 15.) Operator, John C. Ballou, 6 Rogers street, West Quincy, Mass.

The granite (specimen D, XXIX, 80, a), "dark Quincy with minute red dots," is a riebeckite-ægirite granite of dark slightly purplish-gray color, with sparse inconspicuous reddish stains. Its shade is slightly darker than that of 86, a (Merry Mount "dark medium"). Its texture is medium to coarse, even grained, with feldspars up to 0.5 inch and black silicates to 0.3 inch. Its constituents, in descending order of abundance, are: A dark-gray potash feldspar (orthoclase twinned), minutely intergrown with soda-lime feldspar, in places somewhat kaolinized, rarely with hematite stain along its cleavage planes, and inclosing particles of epidote and crystals of riebeckite up to 0.114 millimeter long; smoky quartz of very slight bluish tinge, with abundant cavities up to 0.0094 and exceptionally 0.037 millimeter in diameter, in streaks or sheets intersecting one another at all angles, and with very minute black particles. The quartz incloses a riebeckite crystal 0.178 by 0.0047 millimeter; a little separate soda-lime feldspar (albite to oligoclase-albite); and finally riebeckite, some of it intergrown with ægirite, the latter containing magnetite and carbonate. The accessory minerals are: Zircon and magnetite. The secondary: Kaolin, epidote, hematite, limonite (about the zircon), and calcite.

The contrast is confined to that between the black silicates and the dark gray of the feldspar and quartz with its faint reddish spots.

Mr. George Steiger, chemist, of the United States Geological Survey, extracted 0.28 per cent of CaO (lime) from this stone by means of hot dilute acetic acid, which indicates a content of 0.5 per cent of $CaCO_3$ (lime carbonate) calcite, the presence of which mineral is also shown by the microscope.

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The quarry, opened before 1856, measures about 200 feet from north to south by 100 feet across, but with a recess on the south wall 16 by 18 feet. Its depth is 150 feet.

An interesting cylindrical pegmatite dike, a section of which is exposed at the bottom of the quarry, has been described on page 49. The sheets, from 8 inches to 20 feet thick, increasing in thickness downward, are lenticular, irregular, dipping both north and south. The sheet structure extends at least to a depth of 150 feet from the rock surface, below which there is no parting for 16 feet. Joints A strike about N. 80° W., dip 70° north, are spaced 3 to 30 feet, form a short heading in about the center and one on the northeast side. Joints B strike nearly north, dip 90° and steeply west, form headings at east and west walls, one, 100 feet from west wall, and another (30 to 40 feet wide) 75 feet west of east end. Joints C, striking N. 10° to 30° W., form a heading at the northwest corner of the quarry. The rift is reported as about north-south, the grain as east to west, both vertical. Discoloration is up to 3 inches wide along the joint faces, but is scarcely present on sheet surfaces.

The plant consists of 3 derricks, 2 hoisting engines, an air compressor (capacity 174 cubic feet of air per minute), 3 steam drills, a surfacer, 6 air plug drills, 4 air hand tools, and 2 steam pumps.

Transportation involves cartage of 1 mile to railroad and various distances to cutting sheds.

The product is used mainly for monuments and the inferior stock for paving. The chief market is Philadelphia. Specimen structure: Masonic Building, Philadelphia.

The Djerf & Winquist quarry is on the North Commons, south of Quarry street. (See map, Pl. II, No. 16.) Operator, Djerf & Winquist, Quincy, Mass.

The granite, "extra light," is a riebeckite-ægirite granite of light pea-greenish gray color and medium to coarse texture. It is identical in composition with that of the Lepage quarry (specimen D, XXVIII, 76, a), described on page 112. It owes its green color to the epidotization of the feldspar. The quartz is amethystine, not smoky. The contrast is chiefly between the black silicates and the feldspar, but there is also some between the purplish tinge of the quartz and the light green of the feldspar. Were the stone suitable for monumental work its colors would be attractive on the polished surface.

The quarry, opened in 1887, measures about 300 by 250 feet and 125 feet in depth.

There is a basic dike 6 feet thick, along the south side dipping steeply to the south; a like one a little north of the north wall dips steeply to the north. The sheets, from 2 to 22 feet thick, dip low north. In places they are thick at the top. The quarry is unusually free of joints. Joints A strike about N. 80° W., dip steeply

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north, and from north and south walls only. Joints B strike nearly north, from east and west walls only; one diagonal joint (E) striking N. 45° W., dips 45° to 50° southwest. The rusty stain along sheet surfaces is from one-fourth inch to 6 inches thick.

The plant consists of 2 derricks, 2 hoisting engines, a steam drill, 3 air plug drills, and a steam pump. Compressed air is obtained from the Dell Hitchcock quarry.

Transportation involves cartage of 1 mile to railroad.

The product is used entirely for building and hammered work. Some of it finds a market in New York.

The Sahlsten quarry is on the North Commons, north of Quarry street, about 1,000 feet east of the last. (See map, Pl. II, No. 17.) Operator, Theodore Sahlsten, 34 Mattson street, Quincy, Mass.

The granite, "medium," is a riebeckite-ægirite granite, like that of the Hardwick quarry described below.

The quarry is triangular in area, with sides measuring 100, 75, and 145 feet, respectively, and being from 50 to 75 feet deep.

The sheets from 1 to 10 feet thick, dip 40° southwest. Joints C strike N. 20° W., dip 90°, and are spaced 10 to 20 feet. Joints D, striking N. 55° E., dipping 90°, are spaced 60 feet, and form the south wall. Joints E are diagonal, strike N. 45° W., dip 70° northeast, are spaced 10 to 20 feet, and occur at northeast corner only. Gray knots measure up to 12 by 18 inches. Rusty stain is up to 6 inches thick on the sheet surfaces.

The product is used for monuments and bases, cellar stone, and paving.

The Hardwick quarry is on the North Commons opposite the corner of Quarry and Smith streets. (See map, Pl. II, No. 19.) Operator, C. H. Hardwick & Co., Quincy, Mass.

The granite (specimen D, XXIX, 79, d), "medium," is a riebeckite-ægirite granite of dark, slightly purplish gray color, a trifle darker than 86, a (the "dark medium" of Merry Mount quarry), and a little darker and more purplish than 67, d (the "dark" of Dell Hitchcock quarry). It is of medium, even-grained texture with feldspars and black silicates up to 0.4 inch. Its constituents, in descending order of abundance, are: A medium and dark, slightly purplish gray potash feldspar (orthoclase, usually twinned), always with minutely intergrown soda-lime feldspar and exceptionally with quartz also. In places it is somewhat kaolinized, contains minute epidotes and crystals of riebeckite from 0.0094 to 0.066 millimeter long up to 0.0094 millimeter wide; light smoky quartz with intersecting streaks or sheets of cavities from less than 0.0043 to 0.02 millimeter long, also with very minute black particles; riebeckite and ægirite, the latter with black nonmetallic particles (limonite?); a little soda-lime feldspar (albite to oligoclase-albite). Accessory: Magnetite. Sec-

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ondary: Kaolin, epidote, brownish-yellow fibrous hornblende on riebeckite, and limonite(?).

The contrast is largely between the black silicates and the gray of the quartz and feldspar.

The "light" of the same quarry (specimen D, XXIX, 79, f) is a similar granite of medium gray, inclining to dark, shade without bluish or greenish or purplish tinge, with blue-black and very dark green spots, and of medium texture with feldspar and riebeckite up to 0.4 inch. Its constituents are identical with those of the "medium" already described, except that the feldspar is in places stained with hematite, in others with limonite, proceeding from limonite associated with zircon, and that the ægirite appears to be slightly altered. There is some leucoxene adjacent to ilmenite. The ægirite contains not a little magnetite. Fluorite is among the accessory minerals.

The contrast between the black silicates and the other minerals in the "light" is greater than in the "medium," because the feldspars are lighter.

The "dark" (specimen 79, e) is darker than the "medium" and of same shade as the "dark" of the Granite Railway quarry (68, b), page 109, but of marked purplish tinge. Its texture is medium to coarse.

An analysis of a granite from this quarry is given on page 93.

The quarry, first opened in a small way in 1790, but first operated by the Hardwick family in 1848, measures about 300 feet east and west by 150 feet across, and 125 feet in depth.

The sheets, from 8 inches to 20 feet thick, usually increasing in thickness downward, but in places thin to a depth of 50 feet, are lenticular and horizontal. Joints A, striking N. 80°–85° W., dipping 55°–65° N., are spaced 10, 30, and 60 feet, and form a heading on the west wall. Joints C, striking N. 30° W., dipping 70° SW., are spaced 5, 25, and 150 feet, and form a heading 30 feet wide in the eastern half of quarry. These joints are intermittent. The rift is reported as vertical, with a course not far from N. 30° W., and the grain as horizontal. The boundary between the "medium" and the "light" is irregular. Within the headings the stone has a marked purplish tint from hematite stain. There are rows of riebeckite particles up to half an inch wide with a N. 85° W. course and a dip of 55° S. There are also quartz veinlets with a N. 20° W. course and a dip of 50°–75° E., less than 0.1 inch thick, which in places give way to black silicates. In thin section this black part consists chiefly of quartz, ægirite, and magnetite, with a little zircon (in doubly terminated pyramids), purple fluorite, and carbonate. Aplitic knots of group 1, described on page 95, measure up to 3 feet by 4 inches. Light-gray knots of group 2, with porphyritic feldspar, occur also. Rusty stain along the sheet surfaces is from three-fourths inch to 6 inches thick. The

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drainage of the quarry is said to contain magnesia, iron, and lime. The rock surface is covered with 6 to 16 feet of sand and bowlders.

The plant consists of 5 derricks, 2 hoisting engines, an air compressor (capacity 275 cubic feet of air per minute), 3 steam drills, 4 air plug drills, 3 air hand tools, 5 polishers, and a steam pump.

Transportation involves cartage of 1 mile to railroad and varying distances to local cutting sheds.

The product is chiefly the "medium," but includes some "dark" and "light," the last being used for bases and hammered work. Specimen structures: The addition to Gore Hall at Harvard University, erected in 1870; the custom-house at New Orleans; the Lewis Cass monument at Detroit, Mich.; a 5-foot polished ball in Fairmount Cemetery, Newark, N. J.

The Galvin quarry is on the North Commons, between the McKenzie & Pattison and the Hardwick quarry. (See map, Pl. II.) Operator, The Galvin Granite Company (John P. Galvin), Quincy, Mass.

The granite, similar to that of the Hardwick quarry, is a riebeckite-ægirite granite of dark or medium gray shade.

The quarry is 150 feet square by 100 deep and has 10 feet of stripping.

The chief geological feature is the presence of pegmatite quartz veins at intervals of 2 to 10 feet, striking N. 25° W. and dipping 50° S. 25° W. These veins, up to 1 inch thick, occupy the center of belts of light granite 10 inches wide, and are crossed by vertical subjoints striking about north and not over 1 foot long. They have already been referred to on page 48, and are shown in Pl. III, *B*. The sheets, from 1 to 14 feet thick, are lenticular and horizontal. Joints A strike N. 80° W., dip 90°, and form the north and south walls. B strike north, dip 90°, and form the east wall. C strike and dip with the veins, are spaced 2 to 25 feet and form a heading on the east wall. The rift is reported as vertical, with a N. 80° W. course, and the grain as horizontal, but dips 20° W. when the drilling is done from north to south. Black and gray knots measure from 1 inch up to 2 feet 6 inches in two diameters. Rusty discoloration on sheet surfaces is up to 1 foot thick, in cases even 2 feet.

The plant consists of 2 derricks, 2 hoisting engines, a steam drill, and a steam pump.

The product is carted to local cutters.

The McKenzie & Pattison quarry, idle in 1906, is on the North Commons. (See map, Pl. II, No. 18.) This has on its northwest side quartz veins, like those of the Galvin quarry, striking N. 50° W. and dipping 50° S. 50° W., forming the center of bands of whitish and brownish discoloration.

The Field & Wild quarry is on the North Commons between the last quarry and Cranch street. (See map, Pl. II, No. 20.) Operator, Field & Wild, Quincy, Mass.

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The granite, "dark," "medium," and "light," is a riebeckite-ægirite granite of dark and medium gray shade.

The quarry, opened in about 1840, measures about 600 feet from northwest to southeast by 150 feet across and from 75 to 100 feet in depth.

The rock surface on the northeast side dips steeply east with sheets from 1 to 3 feet thick parallel to it. Some thin sheets occur also in the upper 20 feet on the southwest side. Joints B, striking N. 15° E., dipping 90° and steeply east, spaced 10 to 50 feet, occur at the northwest end only. Joints C, striking N. 15° W., dipping 80° E., are spaced 1 to 8 feet. Joints D, striking N. 45° E., dipping 70°–85° N. 45° W., are spaced 20 to 50 feet. Joints E, striking about N. 45° W., dipping 30°–50° S. 45° W., are spaced 2 to 8 feet. These are conspicuous in the southeastern half of the quarry. Some intermittent joints are coated with riebeckite. The rift is said to vary greatly in direction both in the quarry and in different blocks. There are numerous quartz veins like those at the Galvin and McKenzie & Pattison quarries, striking about N. 45° W., dipping 45° S. 45° W., at intervals of 2 to 25 feet. They are mostly crossed by subjoints 1 foot long, parallel to joints C, an inch or two apart. Some of them have a central fracture. In places they are only one-fiftieth inch thick. A thin section of one shows quartz crowded with cavities in intersecting streaks, crystals of ilmenite (probably), and carbonate. The hand specimen shows fluorite along the edge of the vein. The feldspars adjacent to the vein are traversed by fibrous muscovite, also kaolinized, epidotized, stained with limonite, and otherwise altered. (See p. 95.) Knots up to over 6 inches, some of them of group 2 (p. 95), with prophyritic feldspars, occur.

The plant consists of 3 derricks, 3 hoisting engines, an air compressor (capacity 195 cubic feet of air per minute), a large air drill, 6 air plug drills, 6 air hand tools, and 2 steam pumps.

Transportation involves cartage of 1 mile to railroad.

The product consists of "dark" and "medium" for monuments and "light" for bases, etc. Specimen monuments and structures: The Howe monument at Greenwood Cemetery, New York; Gerkin monument at Great Barrington, Mass.; Joseph Robertson monument at Mount Wollaston Cemetery, Quincy; Payne Building at Cleveland, Ohio.

The above quarries include all which were in operation in 1906 on the North Commons. The following are in West Quincy:

The Wigwam quarry is on Willard street, 570 feet south of West Quincy station. (See map, Pl. II, No. 1.) Operator, Badger Brothers, 107 Willard street, West Quincy, Mass.

The granite, chiefly "dark" and "extra dark," with some "medium" and "light," is a riebeckite-ægirite granite of dark, very dark, or medium bluish gray color and of medium to coarse, even-grained texture.

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Its constituent minerals are similar to those of specimens D, XXVIII, 68, b ("dark"), and D, XXIX, 78, a ("extra dark"), described on pages 107, 109, but the stone is reported as coarser in parts of the quarry than in adjacent quarries. The stone of the east side becomes lighter on exposure, even after polishing.

A polished specimen (D, XXVIII, 73, a) of the "medium" shows the feldspars ranging from a dark gray to a greenish medium gray, and cream colored in spots owing to kaolinization. The contrasts between the black silicates, the grayish quartz and feldspars, and the cream-colored parts of the feldspars are marked and give the stone a mottled shading.

An estimate of the mineral percentages made by applying the Rosiwal method to this specimen, with a mesh of 0.6 inch and total linear length of 20.4 inches, yields these figures:

Estimated mineral percentages in Quincy granite from the Wigwam quarry.

Feldspars	69.51
Quartz	8.43
Riebeckite and ægirite	22.06
	100.00

The quarry, opened between 1820 and 1830, measures about 250 feet in a N. 65° W. direction by 100 feet across, and from 100 to 160 feet in depth.

The sheets at the surface, on the north and west sides, are from 1 to 3 feet thick, and dip 50° northeast. On the south and east sides there are traces of sheet structure in the upper 40 feet but none below that. Joints A, striking N. 83° E. and vertical, are spaced 6 to 20 feet. Joints B, striking N. 10° E. and vertical, are spaced 3 to 18 feet, and form the southwest wall. Owing to its irregular sheets and the spacing of the joints this is technically a "bowlder quarry." The rift is reported as vertical, with an east-west course on the south side, but on the north as dipping steeply north, and the grain as vertical north to south. Black knots are reported up to 6 feet by 2 feet. Greenish and muddy yellow ones of group 3, page 95, measure up to 1 foot in length by a few inches in width. Reddish and greenish spots ("oreï," p. 54) occur in the upper 30 feet. Rusty stain, from one-half inch to 18 inches thick, is abundant along the joint faces.

The plant consists of 5 derricks, 2 hoisting engines, 2 air compressors (capacity 225 cubic feet of air per minute), 3 steam drills, 6 air plug drills, 6 air hand tools, 6 polishers, and a steam pump. The compressors and polishers are run by a 150-horsepower engine.

A siding reaches the quarry, but blocks for finishing are carted a few hundred feet to the cutting shed, which is on the main line.

The product finds its market through local dealers. It consists chiefly of the "dark" and "extra dark" for monuments. Specimens: Polished columns in monument to Solomon Willard, architect of

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BALL OF POLISHED QUINCY GRANITE FROM THE WIGWAM QUARRY.

Diameter, 76 inches; weight, 22,000 pounds.

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Bunker Hill monument, in Hall Cemetery, West Quincy; polished columns in New Orleans custom-house, and a polished ball, 6 feet 6 inches in diameter, at Rock Island, Ill., cemetery. A photograph of this is reproduced in Plate IV.

The Reinhalter quarry is 570 feet south-southwest of the West Quincy station. (See map, Pl. II, No. 2.) Operator, Thomas F. Mannex, West Quincy, Mass.

The granite (specimen D, XXIX, 78, a), "extra dark," is a riebeckite-ægirite granite of very dark bluish gray color and of medium to coarse, even-grained texture, with feldspars up to 0.5 and black silicates up to 0.3 inch. Its constituents, in descending order of abundance, are: A dark and medium gray potash feldspar (orthoclase, mostly twinned) minutely intergrown with soda-lime feldspar, darkened probably by a black mineral in very minute particles. It incloses minute crystals of riebeckite, and particles of epidote; smoky quartz with intersecting streaks and sheets of cavities, very minute black particles and isolated crystals of ægirite; blue-black riebeckite and green-black ægirite, in places intergrown; a little separate soda-lime feldspar (albite to oligoclase-albite). Accessory minerals are: Zircon (rather abundant), ilmenite, and pyrite. Cracks in orthoclase and quartz, intersecting at right angles, probably rift and grain cracks, contain or are crossed by secondary minute riebeckite crystals. The feldspar is much darker on either side of these cracks. The secondary minerals are: Epidote, leucoxene, and part of the riebeckite.

The "medium" of this quarry is a dark, very slightly greenish gray stone of the same texture. Its shade is like the "medium" of the Hardwick quarry (p. 102), but its tint is different. It is darker than the "dark" of the Dell Hitchcock quarry, but differs from that also in tint.

The quarry, opened before 1871, measures 200 feet by 150 on one side and 200 feet on the other, and is 225 in depth.

The sheets, from 14 inches to 20 feet thick, extend to within 50 feet of the bottom or 175 feet from the rock surface. At a point on the east side, 150 feet down, they dip east. On the south side, 175 feet down, they strike N. 85° W. and dip 25°–35° S. Below the sheet structure there is a mass 55 feet thick (100 by 45 feet) without horizontal parting. The joint and rift courses are shown in fig. 9. Joints A dip 90°, form the north and south walls, and recur at intervals of 10 and 35 feet. At 35 feet from the north wall they form a 10-foot heading which extends from a point 100 feet below the surface to the bottom. Joints B are vertical, form the east wall, are intermittent, and are spaced 30 and 60 to 70 feet. The east wall is intersected by a wide heading striking N. 20° E. and dipping steeply east. Joints C dip 90° and form the west wall. Joints D are vertical and exceptional. In about the center of the top of the north wall is a 25-foot heading, which at a point 50 feet down disappears behind it. The heading A

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has "dark" and "medium" granite on its south side and "extra dark" on its north side. The sheets at a point 175 feet down are intersected by several convex southward curving partings, "toe nails." The rift is reported as 90° below, but not quite 90° near the surface, and the grain as horizontal. Black knots are usually but a few inches in diameter, but some 2 feet by 1 foot 6 inches are reported. Gray knots are from one-half inch to 8 inches. Rusty stain measures up to 3 inches on joint faces, but down to one-half inch on sheet faces near the bottom.

The plant consists of 5 derricks, 4 hoisting engines, 3 air compressors (capacity 348, 260, and 80 cubic feet of air per minute, respectively), 4 steam drills, 6 air plug drills, 6 air hand tools, a surfacer, 3 polishers and a steam pump.

Transportation is provided for by a siding at the quarry, a cartage of one-fourth mile to the cutting shed and a shorter cartage from there to the railroad.

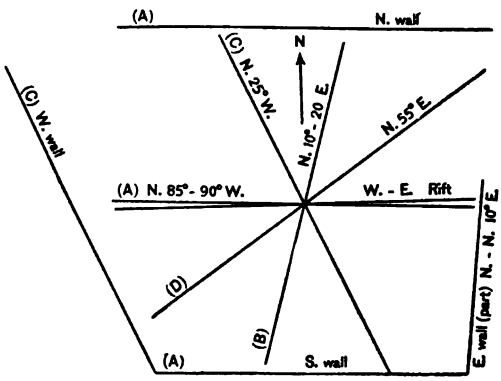

FIG. 9.—Structure at Reinhalter quarry, West Quincy, Mass.

The product consists of "extra dark," "dark," and "medium," but most of it is "extra dark." It is used for monuments and columns. The largest block obtained weighed 50 tons.

The Swingle quarry is about 600 feet southwest of the West Quincy station, and adjoins the Reinhalter quarry on the west. (See map, Pl. II, No. 3.) Operator, J. S. Swingle, Quincy, Mass.

The granite (specimen D, XXVIII, 72, a), "extra dark," is a riebeckite-ægirite granite of very dark bluish gray color, and of medium to coarse, even-grained texture, with feldspars up to 0.5 and black silicates up to 0.3 inch. Its constituents are like those of the adjacent Reinhalter quarry stone (specimen 78, a), page 107.

The contrast in the polished stone is confined to that between the black silicates and the dark gray of the other minerals.

An estimate of the mineral percentages in specimen 72, a, by the Rosiwal method, with a mesh of 0.5 inch and a total linear length of 20 inches, yields these results:

Estimated mineral percentages in Quincy granite from the Swingle quarry.

Feldspars	56.00
Quartz	33.50
Riebeckite and ægirite	10.50
	100.00

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The quarry, opened about 1846, measures about 200 feet from north to south by 175 feet across and 200 in depth.

Irregular horizontal sheets are apparent only to a depth of 100 feet, below which point joints and headings predominate. This is a bowlder quarry and its management is difficult. Joint and rift courses are shown in fig. 10. Joints A are vertical or dip 75° south, form a heading on the north wall, and are spaced 10 to 30 feet. Joints C are vertical and form a heading on the east, 30 feet wide, which separates this from the Reinhalter quarry. Joints D, diagonal, form a heading on the west wall dipping 75° SE., and another extending from east to south walls. They are spaced 2 to 10 feet, and some dip 90°. Joints B, also diagonal, dip 70° east, and form a heading intersecting the south wall and another at the northwest corner. The rift is reported as vertical with a north-south course west of heading C, but with an east-west course east of it. This anomaly may be due to faulting. Knots, green or black, are reported as measuring from 6 inches to 2 feet in diameter. Rusty stain is from one-half inch to 2 inches thick on sheet surfaces at the bottom.

The plant consists of 2 derricks, 2 hoisting engines, an air compressor (capacity 348 cubic feet of air per minute), 4 steam drills, 12 air plug drills, and 4 steam pumps.

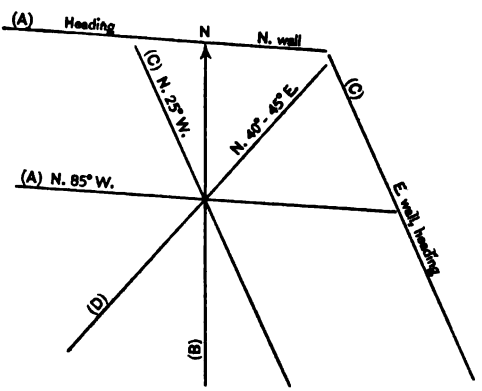

FIG. 10.—Structure at the Swingle quarry in West Quincy, Mass.

Transportation is by a railroad siding for out of town shipments, but by cartage, averaging about 1 mile, to local dealers.

The product is used mostly for monuments. Shipments have been made to Connecticut, Rhode Island, New Hampshire, Maine, New York, New Jersey, Pennsylvania, Delaware, Ohio, Indiana, Illinois, Michigan, Wisconsin, and Missouri. The usual maximum size of blocks quarried is 150 cubic feet, but blocks 40 by 6 by 8 feet are obtainable.

The Granite Railway quarry derives its name from a primitive railroad constructed in 1826 to bring the granite for Bunker Hill Monument from a neighboring opening to tide water at Neponset River. The quarry now worked is about 1,050 feet west-southwest of West Quincy station. (See map, Pl. II, No. 4.) Operator, The Granite Railway Company, Quincy, Mass.

The granite (specimens, D, XXVIII, 68, b, h), "Quincy dark blue railway," is a riebeckite-ægirite granite of dark bluish gray color, and medium to coarse, even-grained texture, with feldspars up to 0.5 inch

and black silicates up to 0.3 inch. Its constituents, in descending order of abundance, are: A dark bluish-greenish gray, black-streaked potash feldspar (orthoclase, in twins), minutely intergrown with soda-lime feldspar, apparently darkened by microscopic black particles and also somewhat kaolinized, containing blue-brownish crystals of riebeckite down to 0.009 millimeter long, also irregular particles of green epidote and some slender ones up to 0.37 millimeter long arranged either along the twinning plane or the plane of intergrowth with the soda-lime feldspar. The black streaks are due to clusters of radiating fibrous crystals of a brown hornblende; smoky quartz with intersecting streaks or sheets of cavities, from less than 0.0028 to 0.0085 millimeter, also with abundant microscopic black particles; blue-black riebeckite and green-black ægirite in many cases intergrown. Basal sections of the latter appear corroded; separate soda-lime feldspar (albite to oligoclase-albite) in very small amount. The accessory minerals are: Ilmenite, zircon in doubly terminated pyramids, and apatite. The secondary: Epidote, kaolin, leucoxene, hematite and limonite stain (rare), brown hornblende, and, as shown by test, calcite.

The contrast between the smoke shade of the quartz and the slightly bluish-greenish gray of the feldspar is small. It lies mainly between these and the black silicates.

An estimate of the mineral percentages by the Rosiwal method yields the following results, with a mesh of 0.4 inch and a total linear length of 71.2 inches.

Estimated mineral percentages in Quincy granite from the Granite Railway quarry.

Feldspars	58.79
Quartz	33.74
Riebeckite and ægirite	7.47
	100.00

Of course the last figure does not include the microscopic particles of the two black silicates.

Mr. E. C. Sullivan, chemist, of the United States Geological Survey, extracted 0.13 per cent of CaO (lime) from this granite by means of hot dilute acetic acid, which indicates the presence of 0.25 per cent of $CaCO_3$ (lime carbonate) calcite.

The "extra dark" of the same quarry (specimen D, XXVIII, 68, c) is darker than 68, b, but a trifle lighter than the "extra dark" of the Swingle quarry. The feldspar seems to be darkened by more brown hornblende and more abundant other black particles. There is also a dark orange hornblende. The minute riebeckite crystals and long slender epidote particles are both arranged with reference to the twinning of the feldspars. An ægirite particle (0.2 by 0.14 millimeter) coated with radiating crystals of riebeckite (up to 0.09 millimeter

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long) occurs within a quartz area. Purple fluorite is mingled with the riebeckite.

The quarry, opened in 1826, is roughly T-shaped, the top of the T measuring about 800 feet N. 75° W. by 450 feet N. 10° E., and the stem being about 250 by 20 feet. Its depth ranges from 50 to 70 feet, but 30 feet of rock had been removed from the present edge of the quarry. In 1906 a mass about 100 feet square, rising 30 to 40 feet above the edge and devoid of sheet structure, projected into the quarry west of the stem of the T.

A 15-foot diabase dike dipping 60° NNE, with a greenish rim a foot thick on its under side, bounds the quarry on the southwest. (See p. 95.) The granite under the dike has three sets of joints, one dipping about 50° in the opposite direction, one parallel to the dike, and a third striking N. 22° E. with the dip of the dike. The sheets are in places regular, in other places they are in short lenses, and in others are altogether absent. This is a bowlder quarry. The courses of dike, joints, and rift are shown in fig. 11. Joints A dip 55° southwest, form a heading on the northeast, and are spaced 1 to 12 feet. Joints B are vertical, form the east and west walls, and are spaced irregularly up to 300 feet. Joints C, diagonal and dipping 70° west, form a heading at the west angle of the T in the projecting mass. Joints D, diagonal and dipping about 55° east, are coated with riebeckite and hence are called "black seams." (See p. 60.) They occur intermittently on the south side of the quarry. The rift is reported as vertical with a N. 80° W. course, and the grain as also vertical at right angles to it, but feeble. In the western part of the top of the T there is a mass of hematitic and chloritic granite ("oreï") extending 30 feet down from the surface. This is described fully on page 54. Knots of dark-gray shade measure up to 12 by 6 inches. Rusty stain is from 3 to 12 inches thick on joint and sheet faces in the deeper part of quarry.

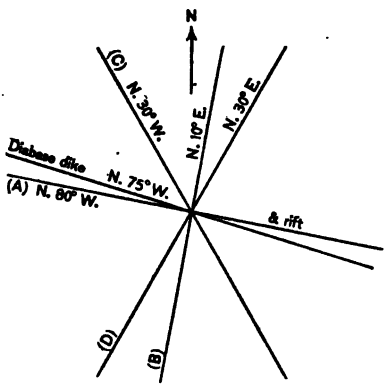

FIG. 11.—Structure at Granite Railway quarry, West Quincy, Mass.

This company operates another quarry, opened in 1905, known as No. 4, Nos. 1, 2, and 3 being designations of parts of the last quarry. No. 4 lies west of the Swingle quarry and measures about 200 feet N. 15° E. by 75 to 100 feet east and is from 15 to 40 deep. The sheets, from 6 inches to 8 feet thick, are horizontal or dip north with the hill

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surface. The Bunker Hill quarry, which furnished stone for that monument, lies about 1,800 feet south of No. 4, but is now idle. (See map, Pl. II.)

The plant at these quarries includes 8 derricks, 7 hoisting engines, 4 steam drills, and 4 steam pumps. The cutting shed at the foot of the hill contains an air compressor (capacity, 630 cubic feet of air per minute), 40 air-plug drills, 15 air hand tools, 3 surfacers, 8 polishers, and 2 overhead cranes of 10 and 20 tons capacity.

Transportation is effected by a siding from the New York, New Haven and Hartford Railroad.

The product is used mostly for monuments and polished building fronts. Much of it goes to the Middle West. Specimens: The Bunker Hill Monument and a polished monument 23 feet high to W. C. Whitney, Secretary of the Navy, at Woodlawn Cemetery, New York. The waste is used for cellar stone, riprap, and paving.

The Lepage quarry is between the Granite Railway and the Cashman quarries. (See map, Pl. II, No. 5.) Operator, Lepage Granite Company, West Quincy, Mass.

The granite (specimen D, XXVIII, 76, a), "extra light," is a riebeckite-ægirite granite of light pea-greenish gray color, and medium to coarse even-grained texture, with feldspars up to 0.5 inch and black silicates to 0.4 inch. Its constituents, in descending order of abundance, are: A light pea-green potash feldspar (orthoclase, mostly twinned), minutely intergrown with soda-lime feldspar. It is somewhat kaolinized and more epidotized than that of the gray granites of the region, but contains far fewer minute crystals of riebeckite. The epidote is apt to be parallel to the twinning plane of the orthoclase or the plane of intergrowth of the two feldspars; amethystine quartz, showing effects of strain, and containing intersecting streaks and sheets of cavities, also minute black particles; blue-black riebeckite and green-black ægirite, in cases intergrown; soda-lime feldspar (albite to oligoclase-albite). The accessory minerals are: Zircon, pyrite, and fluorite. The secondary: Kaolin, epidote, carbonate, limonite, and slender crystals of orange-yellow hornblende radiating from ægirite particles.

As pointed out on page 53, the color of the granite and its feldspar seems to be due to the increase of epidote and to the absence or alteration of the minute riebeckite crystals. Kaolinization has also lightened its shade.

The chief contrast is between the black silicates and the rest of the stone, the next between the feldspar and quartz. It takes a poor polish and is only used for bridges, curbing, paving, etc. On the north side of the quarry there is some "dark" adapted to monumental work.

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The quarry, opened in 1905, is about 100 feet north to south by 60 to 80 feet across and from 30 to 45 feet deep.

The sheets, from 1 to 5 feet thick, dip 10° south. Joints A strike N. 80°–85° W., dip 70°–80° north, form the south wall, and are spaced 4 to 10 feet. Joints C strike N. 15° W., dip 90° and 70° east, form the west wall and a heading on the east wall, and are spaced 3 to 10 feet. The rift is reported as 90° with an east-west course, and the grain as vertical, north-south. The abundance of joints has proved a drawback. Rusty stain, already referred to on page 57, is from 1 to 2 inches thick. Blocks of the pea-green stone bordered by the bright yellowish-brown stain afford striking contrasts. (Specimen D, XXVIII, 76, b.)

The plant includes a derrick, hoisting engine, steam drill, and steam pump. Two plug drills are operated by compressed air from the Granite Railway plant.

Transportation involves cartage of 1 and 2 miles.

The product consists of some dark for monuments, but of more "extra light" for construction and street work.

The Cashman quarry is about 1,800 feet west of the West Quincy station. (See map, Pl. II, No. 6.) Operator, John Cashman, 49 Cross street, West Quincy, Mass.

The granite, "extra dark," "medium," and "extra light," is a riebeckite-ægirite granite of very dark, or medium bluish gray, or of light pea-greenish gray color, and of medium to coarse, even-grained texture. Its constituents correspond to those of the several varieties of Quincy granite as described on pages 109, 110, 112.

The quarry, opened about 1876, is of irregular area owing to several offsets or projecting parts on the north, east, and west sides. It is roughly about 350 feet long, north-south, by 225 feet across and from 70 to 100 feet deep. Mr. Cashman controls and operates only the southern two-thirds of the opening, the rest being idle.

The sheets, from 1 to 5 feet thick, are lenticular and flat on the south side, but dip north with the surface at the north. They extend to the bottom of the quarry. Joints A strike nearly east-west, dip steeply north or south, form a heading on the north side, and are spaced 10 to 75 feet. Joints B strike about north, dip 90°, form headings on east side and 35 feet west of it, and are spaced 10 to 30 feet. The rift is reported as vertical, about east-west, but in places dipping away from the vertical, north or south. When split from the side the rift in those places is vertical. The grain is said to dip steeply with north-south course. A workman stated that the rift in the "extra light" was superior to that in the dark stone, and the blocks in sight showed smooth rift breaks. The "extra light" occurs at both north and south ends of the quarry and the dark in the center. Near

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a heading at southeast corner the granite is hematitic ("oreï"). (See p. 54.) Rusty stain is from 1 to 3 inches thick on both light and dark stone. The rock surface is covered with 5 to 10 feet of fragments of weathered granite, sand, and bowlders.

The plant consists of 3 derricks, 3 hoisting engines, 2 swinging engines, an air compressor (capacity, 134 cubic feet of air per minute), 2 steam drills, 4 air plug drills, and 2 steam pumps.

Transportation involves cartage of 2 miles.

The product is monumental and bridge work, the former being four times more in value than the latter. Specimen structures: Arch bridge across Furnace Brook Parkway in West Quincy; five bridges between South Braintree and Whitman on the Plymouth division of the New York, New Haven and Hartford Railroad.

The Savo quarry is about four-fifths mile west-northwest of West Quincy station. (See map, Pl. II, No. 8.) Operator, Savo Granite Company, 16 Quarry street, Quincy, Mass.

The granite (specimen D, XXIX, 84, a) is an altered riebeckite-ægirite granite of pinkish medium gray color and medium to coarse even-grained texture, with feldspars up to 0.5 inch and greenish silicates up to 0.2 inch. Its constituents are, in descending order of abundance: A light-pinkish, not transparent potash feldspar (orthoclase, twinned) with minutely intergrown soda-lime feldspar, considerably kaolinized, but containing little epidote and no riebeckite. Its pinkish color must be attributed to hematite, arising either from the oxidation of FeO in the feldspar or of magnetite in the other particles; smoky quartz with intersecting streaks or sheets of cavities and minute black particles; riebeckite and ægirite altered to quartz, magnetite, carbonate, epidote and in some cases chlorite; a little soda-lime feldspar (oligoclase-andesine). The accessory minerals are: Zircon (rather large), and fluorite. The secondary: Kaolin, epidote, carbonate, magnetite (some in crystals), chlorite, and hematite. A veinlet crossing several feldspars consists for a part of its course of epidote, in another part of quartz and in another of calcite. (See further on this granite, p. 54.) The pink tint fades somewhat on exposure.

The quarry, opened in 1905, measures about 135 feet N. 55° W. by 50 feet across and 40 feet in depth.

The sheets, from 1 to 8 feet thick, dip 45° N. 25° E., without reference to present surface. Joints A strike N. 70° W., dip about 60° N. 20° E., and S. 20° W. Of this set there are two at the south end. Joints C strike N. 30° W., dip 90° and steeply west, and form east and west walls. The pink granite occupies the southern half of the quarry and the pea green the northern half. The rift is reported as vertical, north-south, and the grain as horizontal. Rusty stain is from 8 to 12 inches thick. The stripping is from 8 to 13 feet thick.

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The plant consists of 2 derricks, a hoisting engine, a steam drill, and a steam pump.

Transportation involves cartage of nearly 1½ miles to West Quincy.

The product up to October 17, 1906, had been confined to cellar stone and curbing. It was hoped, however, that as the quarry deepened unaltered gray granite suitable for monumental use would be found. If the pink is part of a zone of slightly metamorphosed surface alteration that hope will be realized.

The Gold-leaf quarry is 4,500 feet N. 80° W. from the West Quincy station. (See map, Pl. II, No. 7.) Operator, The Quincy Quarries Company, Quincy, Mass.

The granite (specimens D, XXVIII, 71, a, b) "Gold-leaf Quincy" is a riebeckite-ægirite granite of medium bluish-green gray color (a trifle lighter than 67, c, the "light" of Dell Hitchcock quarry) speckled with black and yellow brown. Its texture is medium to coarse, even grained, with feldspars up to 0.5 inch and black silicates to 0.3 inch, and yellow brown stains to 0.5 inch, but the quartz areas are finely granular. Its constituents, in descending order of abundance, are: Medium bluish-green-gray potash feldspar (orthoclase, twinned) minutely intergrown with soda-lime feldspar, in places granulated, somewhat kaolinized and epidotized, and containing many minute crystals of riebeckite, to which with the epidote the feldspar owes its peculiar color; quartz, clear to light smoky, almost without cavities, all granulated in particles mostly under 1 milimeter, rarely 2 millimeters in diameter; blue-black riebeckite and green-black ægirite, in places associated with limonite (and hematite?); soda-lime feldspar (albite and probably oligoclase-albite) in small amount. Fluorite is accessory. Secondary limonite occurs in irregular areas, mostly not related to the particles of black silicate, and this produces the yellow-brown stains. The epidote is secondary also.

An estimate of the mineral percentages by the Rosiwal method, with a mesh of 0.5 inch and a total linear length of 74 inches, yields these figures:

Estimated mineral percentages in Gold-leaf Quincy granite.

Feldspars	67.37
Quartz	23.01
Riebeckite and ægirite	9.62
	100.00

As compared with other Quincy granites these proportions approximate those of the Wigwam quarry stone. It is the lightest of the Quincy monumental granites. The contrasts between the light bluish green of the feldspar and the black particles and the yellow-brown stains are marked. The minute particles of granulated quartz

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reflect the light and, as it were, spangle the surface, and where the limonite stain coincides with the quartz areas the yellow brown spots are the more conspicuous. Hence the trade name "Gold leaf." It takes a high polish, but as small pits are apt to appear in the quartz areas, probably owing to the dropping out of minute quartz particles, it seems better adapted to indoor ornamentation.

The quarry is about 125 feet square, and from 20 to over 50 in depth.

Joints A strike N. 80° W., vertically and steeply north, form the north wall and are spaced about 50 feet. Joints C strike N. 10° W., dip 30° east, form 3 headings in the eastern half, and are spaced 4 to 15 feet. These apparently serve as, or in fact are, sheets. Fine-grained gray knots of group 1 (p. 95), measure 6 inches in diameter.

The Quincy Quarries Company owns a large cutting plant a few hundred feet southeast of this quarry, which in 1906 was let to Robert Cantley. It includes an overhead crane of 20 tons capacity, an air compressor (capacity 290 cubic feet of air per minute), one air plug drill, 35 air hand tools, 5 lathes for stones 21 feet by 5 feet 6 inches, 6 double polishing lathes for stone up to 22 feet by 5 feet 6 inches, one for balls, balusters, and small work, 3 polishers, a stone crusher, and a 151-horsepower engine for driving the lathes, polishers, etc.[a]

This quarry was idle in 1906 as were also 2 other openings controlled by the same company, situated a few hundred feet south and southeast of it.[b] Twelve columns, 19 feet 6 inches by 3 feet 4 inches have been obtained from the "Gold-leaf" quarry.

Transportation from both quarry and cutting shed is by sidings connected with the Granite branch of the New York, New Haven and Hartford Railroad, as shown in Pl. II.

The Rogers quarry is at the north foot of the "Blue Hills," 1,500 feet northwest of the West Quincy station on Willard street. (See map, Pl. II, No. 9.) Operator, The Quincy Quarries Company, Quincy, Mass.

The granite (specimen D, XXVIII, 70, d), "extra dark," is a riebeckite-ægirite granite of very dark purplish gray color and of medium to coarse texture, with feldspars up to 0.5 and black silicates up to 0.3 inch. Its constituents are like those of the Reinhalter and the Granite Railway "extra dark" granite, described on pages 107, 109. The feldspars have more whitish kaolinized streaks, hence the general shade is slightly lighter than the granites referred to

[a] In 1906 500 balusters of Milford, Mass., pink granite were being finished at this plant for the Pennsylvania Terminal Station at New York under a contract with the Milford Stone Company. (See p. 78.)

[b] One of these openings, known as the Fuller quarry (Pl. II, No. 21), is owned by the Quincy Granite Company but let to the Quincy Quarries Company. It was opened about 1850, and measures about 600 by 400 feet and 150 feet in depth. The Quincy Granite Company now confines itself to cutting and polishing.

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(78, a, and 68, c), and minute hematitic stains account for its more purplish hue. This quarry also yields the "dark."

The quarry, opened in 1832, measures about 600 feet from north to south by 175 feet across and from 40 to 150 feet, or an average of 95 feet in depth.

The sheets are short and thick lenses, which render the structure obscure and irregular. Joint courses are shown in fig. 12. Joints A dip 90° or steeply north and are spaced 10 to 20 feet. Joints B, dipping steeply east, form headings on east and west walls and are spaced 10 to 20 feet. Joints C, dipping 50° east, form a heading at the northwest corner, the faces of which are coated with riebeckite, and are spaced 6 inches to 4 feet. (See on these black joints, p. 60.) This heading intersects a heading of B. Joints D, diagonal, dip 40° S. 45° W., and are spaced 2 to 20 feet. At the south end several faces dipping 30°–60° N. may belong to A. The rift is reported as vertical with east-west course and the grain as also vertical, at right angles, but feeble.

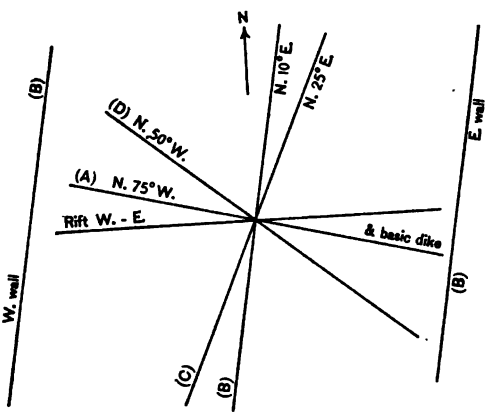

FIG. 12.—Structure at Rogers quarry, West Quincy, Mass.

A basic dike, 2 feet thick, at the north end dips 65° north. Fine-grained aplitic knots probably of group 1, page 95, occur. The largest knot reported was 3 by 1½ feet. Rusty stain is from 1 to 12 inches thick. In places all the granite to a depth of 30 feet is somewhat stained, but in others good stone occurs at the top. At the south end, west side, the granite upon exposure discolors readily to a medium slightly olive gray. Specimen D, XXVIII, 70, b, described on page 54, had been exposed three years at a point 30 feet down. In thin section the stain is seen to proceed from particles of riebeckite and ægirite. This feature marked the stone at that point as far down as excavations had gone in 1906.

The plant consists of 5 derricks, 5 hoisting engines, an air compressor (capacity 290 cubic feet of air per minute), 2 steam drills, 8 air plug drills, and a stone crusher (capacity 150 tons per day).

Transportation is effected by a siding from the New York, New Haven and Hartford Railroad.

The product is used for monuments, and the waste for road material, etc.

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The following two quarries are in Milton:

The Mount Pleasant quarry is at the northwest foot of the Blue Hills, in Milton Township, on Lyman road, off Pleasant street. (See map, Pl. II, No. 11.) Operator (1906), The Mount Pleasant Quarry Company, H. H. Folsom, receiver, East Milton, Mass.

The granite (specimen D, XXIX, 85, a), "dark Quincy," is a riebeckite-ægirite granite of dark bluish gray color, a trifle lighter than 68, b ("dark blue railway"), and with a more bluish tinge. Its texture is medium to coarse, even-grained, with feldspars up to 0.5 inch and black silicates to 0.3 inch. Its constituents, in descending order of abundance, are: A medium to dark bluish gray potash feldspar (orthoclase, mostly twinned) minutely intergrown with soda-lime feldspar, in places somewhat kaolinized, with unusually abundant minute crystals of riebeckite and some particles of epidote, also minute orange-colored hornblende crystals; quartz, dark smoky, with very slight bluish tinge, containing minute cavities and black particles in intersecting streaks and sheets; blue-black riebeckite and green-black ægirite in cases intergrown; soda-lime feldspar (albite and probably oligoclase-albite) in very small amount. Accessory: Fluorite and allanite. Secondary: Kaolin, epidote, calcite, limonite, and probably the orange hornblende.

The blueness of this stone is clearly due to the abundant riebeckite crystals in the feldspars. This comes out on the polished face. (See specimen 88, a, which is identical, but from the adjoining quarry, p. 119.)

Mr. George Steiger, chemist of the United States Geological Survey, extracted from this granite by means of hot dilute acetic acid 0.15 per cent of CaO (lime), which indicates a content of 0.26 per cent of $CaCO_3$ or calcite, the presence of which mineral is also shown by the microscope.

The quarry, opened in 1901, measures about 125 by 100 feet and 100 feet in depth.

The sheets, from 5 to 27 feet thick, are horizontal and turn to dip gently east. Some of the sheet surfaces on the west side are coated with riebeckite. (See p. 60.) Joints B strike N. 10° E., dip 90° and steeply east, form the east wall, and are spaced 5 to 11 feet. Joints A strike N. 60° W., form a heading on the south side, and are spaced 2 to 15 feet. Joints E, diagonal, strike about northwest and form a heading near the west wall, which has a dark-bluish stone northeast of it, but inferior light stone southwest of it. Black riebeckite-coated joint and sheet faces abound in this part. The rift is reported as vertical with a nearly N. 10° E. course. Rusty stain is up to 2 inches thick on the lower sheets. The surface has from 5 to 10 feet of stripping.

The plant includes 3 derricks, a hoisting engine, a hand derrick, 3 steam drills, and a pump.

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Transportation involves cartage of 2¼ miles to the railroad at West Quincy or of 3 miles to cutting sheds at Quincy.

The chief product is used for monuments.

The Maguire & O'Heron quarry is at the northwest foot of the Blue Hills, in Milton Township, about 800 feet southwest of the last quarry, off Pleasant street. (See map, Pl. II, No. 10.) Operator, Maguire & O'Heron, East Milton, Mass.

The granite (specimen D, XXIX, 88, a), "dark Quincy," is a riebeckite-ægirite granite of dark bluish gray color like that of the adjoining Mount Pleasant quarry (specimen 85, a). Its texture and constituents are also identical.

The polished face brings out the marked bluish tinge of the feldspars, which are streaked with whitish kaolinized parts and contrast somewhat with the smoky quartz, but much more with the black silicates. This stone differs from the "dark blue railway" (specimen D, XXVIII, 68, h, p. 109) by its slightly more bluish tinge, which is due to the greater abundance of microscopic riebeckite crystals in the feldspars.

An estimate of the mineral percentages by the Rosiwal method, with a mesh of 0.5 inch and a total linear length of 20 inches, yields these figures:

Estimated mineral percentages in Quincy granite from the Maguire & O'Heron quarry.

Feldspars	55.80
Quartz	33.10
Riebeckite and ægirite (excluding microscopic particles)	11.10
	100.00

The quarry, opened in a small way about 1882, but in a larger way in 1901, measures about 250 feet, N. 35° E. by from 75 to 150 feet across and 70 feet in depth. Its width at north and south ends is irregular, averaging about 100 feet.

The sheets, from 3 to 15 feet thick, dip as high as 20° southwest. Joints B strike north, dip steeply east, form a 50-foot heading on the southwest wall, and are spaced 3 to 20 feet. Joints C strike N. 20°–25° W., dip 75° ENE., and form a heading in the middle of the south end. Joints D strike N. 35° E., dip vertically and steeply west, form the east and west walls, and are spaced 3 to 100 feet. The rift is reported as nearly vertical, with a north course, and the grain as horizontal. Quartz veins, from 1 to 3 inches thick, dipping 30° southeast and inclosed in belts of whitish discoloration, recur at intervals of 3 to 18 feet. (See pp. 48, 53.) Rusty stain is from 3 to 18 inches thick on the lower sheets.

The plant consists of 3 derricks and 2 hoisting engines, 2 air compressors (capacity 130 and 230 cubic feet of air per minute), a steam drill, 12 air plug drills, 18 air hand tools, 3 polishers, a steam pump, an overhead crane (capacity 15 tons), and a 35-horsepower engine for the cutting shed.

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Transportation involves cartage of nearly a mile and a half to the cutting shed at East Milton and of another mile to the railroad at West Quincy.

The product is used mostly for monuments and the waste for cellar stone. Specimen monuments: The Bradley monument, at Purdy Station N. Y., monument to Samuel Neilson, the Irish patriot, at Poughkeepsie, N. Y.; the Long monument, at Mansfield, Ohio; the Patterson monument, at Ashland, Pa.; the Meehan monument, at St. Joseph's Cemetery, Boston, and the Mead Chapel, at Lake Waccabuc, N. Y.

The last of the Quincy quarries is on the southeast side of the Blue Hills.

The Sartori quarry is on Pine Hill, in Quincy Township, close to the Braintree line. (See map, Pl. II, No. 12.) Operator, Angelo Sartori & Brothers, 66 West street, West Quincy, Mass.

The granite (specimen D, XXIX, 82, a) is an altered riebeckite-ægirite granite of very dark dull greenish-brownish gray, almost without contrasts, and of medium to coarse even-grained texture, with feldspars up to 0.5 inch and altered black silicates up to 0.3 inch. Its constituents, in descending order of abundance, are: A dark greenish-brownish gray nearly opaque potash feldspar (orthoclase, twinned), some of which is minutely intergrown with soda-lime feldspar. It is mostly much kaolinized and in places much micacized, and here and there is stained with hematite (no epidote or riebeckite crystals were detected in it); smoky quartz, in places pinkish from hematite stain, with intersecting streaks or sheets of cavities and minute black particles; riebeckite and ægirite particles completely altered to masses of greenish biotite, magnetite (mostly octahedral), carbonate, and quartz with some chlorite or delessite; very little soda-lime feldspar (oligoclase); magnetite, zircon, allanite, and fluorite. There are also (spherulites) brownish balls of radiating fibrous crystals, 0.02 to 0.1 millimeter in diameter, some of which polarize like zircon. Secondary: Biotite, a white mica, carbonate, chlorite or delessite, hematite, and magnetite.

This granite differs by its greenish-brownish color from all the other Quincy granites, although microscopically it approaches the pinkish of the Savo quarry (p. 114), but it differs from that by the different alterations of its feldspars and black silicates.

The quarry, opened in 1903, measures 50 by 30 feet, and 15 to 20 feet in depth.

This is a bowlder quarry. Joints A strike N. 77° W., dip 45° NNW., and are spaced 3 to 10 feet. Joints C strike N. 10° W., dip 90°, and are spaced 3 to 20 feet. The rift is reported as parallel to A.

The product in 1906 had been found adapted only to bases, curbing, and paving.

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ROCKPORT.

Topography.—The township of Rockport occupies the eastern and northern part of that insular mass on the Atlantic coast known as Cape Ann. (See Gloucester sheet of United States Geological Survey topographic atlas.) It is in the county of Essex, in northeastern Massachusetts, in a region of low, roundish or oval, granitic or sandy hillocks, never exceeding 180 feet in height, and of marshes and bowlder-strewn sand flats. The most conspicuous of these hillocks is Pigeon Hill, about a mile north of Rockport village, which is regarded as a drumlin. The quarries are in the northern part of the Cape, scattered along the shore or within three-quarters mile of it, from Rockport to Bay View. (See fig. 13.)

General geology.—The physiography and geology of Cape Ann have been interestingly described by Shaler and Tarr.[a]

The entire Cape is represented in Shaler's map, Pl. LXXVII, as of granite but traversed at very frequent intervals by diabase dikes and at a few points by quartz porphyry dikes. According to Sears's geological map of Essex County, hornblende granite covers Halibut Point, Rockport, and the area half a mile east of Bay View, but a quarter of a mile east of Bay View there is a small area of "augite syenite."[b]

The geological age of the granite is not yet fully determined. The basic dikes may be Triassic. They range from one-half inch to 40 feet in width. Of 361 observed by Shaler and Tarr 266 lie in the northwest quadrant and more than half in the 45 degrees between north and northwest. They conclude from numerous observations of dike and joint courses that the number of dikes does not appear to have been determined by the number of incipient fissures afforded by the joints; in other words "that the conditions which guided the direction of the dikes were probably due to some feature or condition not inherent in the joints themselves."

Description of Rockport granite.—The more recent scientific accounts of Rockport granite are those of Wadsworth, Merrill, Washington, and Sears.[c] Cooke, Clarke, Penfield, and Forbes have described certain new or unusual minerals in Rockport granite.[d]

The following epitomizes the descriptions of rough and polished specimens and thin sections of this granite from all the quarries as

[a] See Shaler, N. S., The geology of Cape Ann, Mass.: Ninth Ann. Rept. U. S. Geol. Survey, 1889, pp. 529–611.

[b] Sears, J. H., The physical geography, geology, mineralogy, and paleontology of Essex County, Mass.: Essex Institute, Salem, Mass., 1905.

[c] Wadsworth, M. E., Notes on the petrography of Quincy and Rockport: Proc. Boston Soc. Nat. Hist., vol. 19, 1881; Merrill, G. P., Report Smithsonian Institution, 1885, 1889, pt. 2, p. 419; Washington, H. S., The petrographical province of Essex County, Mass.: Jour. Geol., vol. 6 (8), 1898, pp. 790–796; Sears, J. H., op. cit., pp. 150, 153.

[d] Cooke, J. P., On cryophyllite, a new mineral species of the mica family with some associated minerals in the granite of Rockport, Mass.: Am. Jour. Sci. (2), vol. 43, 1867, pp. 217–230; also, On danalite from Rockport: Ibid., July, 1866 (p. 73); Clarke, F. W., On cryophyllite from Rockport: Ibid. (3), vol. 32, 1886, p. 358; Penfield, S. L., and Forbes, E. H., Fayalite from Rockport, Mass., etc.: Ibid. (4), vol. 1, 1896, pp. 129–131.

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described on the following pages. Analyses, mineral percentages, and results of physical tests follow the rock description.

Rockport granite is of two sorts, the first and most abundant, known commercially as "gray granite," is a hornblende granite of

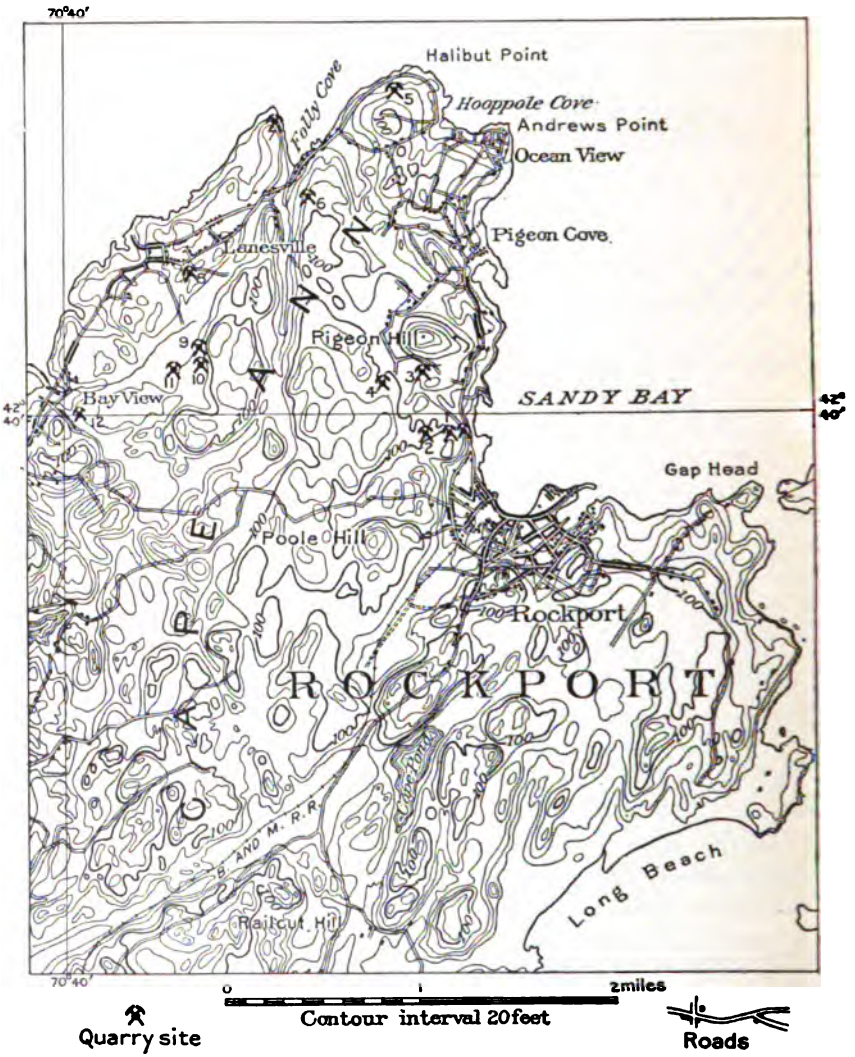

FIG. 13.—Map of part of Cape Ann, Mass., showing the locations of Rockport granite quarries. 1, Flat Ledge quarry, Rockport Granite Company. 2, Upper Pit, Rockport Granite Company. 3, Pigeon Hill quarry, Pigeon Hill Granite Company. 4, Upper quarry of Pigeon Hill Granite Company. 5, Babson Farm quarry, Rockport Granite Company. 6, Nickerson quarry, W. E. Nickerson. 7, Breakwater quarry, Breakwater Construction and Engineering Company. 8, Canney quarry, Edwin Canney. 9, Devils Rock quarry, William R. Cheves. 10, Cheves Green Granite quarry, William R. Cheves. 11, Blood Ledge quarry, Rockport Granite Company. 12, Deep Pit, Rockport Granite Company.

medium gray shade (in places with slight greenish or bluish tinge) spotted with black. Its texture is medium to coarse and even grained, with feldspars up to 0.3 or 0.5 inch, and hornblende up to 0.2

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inch. Its constituents, in descending order of abundance, are a light gray potash feldspar (orthoclase with or without microcline) of a silghtly greenish or bluish or buff tinge, generally twinned and minutely intergrown with soda-lime feldspar (albite to oligoclase-albite), more or less kaolinized; quite smoky quartz with abundant cavities (many with liquid and vacuoles), from 0.0043, or under, to 0.02 milimeter in diameter, mostly in sheets; black hornblende, in places with a little bluish-black riebeckite (p. 91); very little separate soda-lime feldspar like above; and very little black mica (biotite or lepidomelane).[a] The accessory minerals are: Magnetite, pyrite, allanite, fluorite, zircon, and apatite. The secondary are: Hematite, limonite, kaolin, some black hornblende, and calcite.

Estimates of the mineral percentages by the Rosiwal method yield the following results:

Estimated mineral percentages in "Rockport Gray Granite."

	Average.
Feldspar, 55.50 to 59.60	57.97
Quartz, 33.88 to 38.90	35.82
Hornblende and mica, 5.60 to 7.26	6.20

Rockport granite is said to be "hard." These estimates show quartz averaging 35.83 per cent, or if the green of Bay View, given beyond, be averaged with the gray, 34.85 per cent, whereas the average amount of quartz in five tests of Quincy granite is 30.60 per cent (p. 93), in Conway red granites 28.62 per cent (p. 180), and in the Redstone granite of Westerly, R. I. (p. 200), 29.87 per cent. This extra 6 per cent of quartz may be sufficient to account for the hardness.

H. S. Washington[b] gives the following analysis of Rockport granite:

Analysis of Rockport granite.

[By H. S. Washington.]

SiO_2 (silica)	77.61
TiO_2 (titanium dioxide)	.25
Al_2O_3 (alumina)	11.94
Fe_2O_3 (iron sesquioxide)	.55
FeO (iron oxide)	.87
MnO (manganese oxide)	Trace.
MgO (magnesia)	Trace.
CaO (lime)	.31
Na_2O (soda)	3.80
K_2O (potash)	4.98
H_2O (water) 110−	Trace.
H_2O (water) 110+ignition	.23
	100.54

Specific gravity 2.618 at 18° C.

[a] Washington, H. S., op. cit., p. 793, reports 2 varieties of biotite, one very pale green, probably cryophyllite of Cooke, the other darker greenish gray, lepidomelane (annite). Clarke, F. W., op. cit., shows that several varieties of biotite occur.

[b] Op. cit., p. 793. On p. 794 he gives these estimates of the mineral percentages based partly on the analysis and partly on microscopic observation: Feldspars 50.2 per cent, quartz 35.5 per cent, hornblende and two biotites 3.8 per cent, accessory minerals 0.5 per cent. The figure for quartz agrees very closely with that obtained by the Rosiwal method.

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Messrs. Steiger and Sullivan, chemists, of the United States Geological Survey, find that this granite contains from 0.14 to 0.20 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates the presence of from 0.25 to 0.35 per cent of $CaCO_3$ (lime carbonate), calcite. (See pp. 125, 129.)

Owing to the black silicate being almost entirely hornblende the stone takes a very high polish. The contrasts of shade between the gray feldspar, smoky quartz, and black hornblende are much more marked on the polished than on the rough face.

The other variety of Rockport granite, known as "green granite," is also a hornblende granite, but of somewhat dark olive-gray color spotted with black.

Its texture is medium to coarse, even grained, with feldspars up to 0.3 and 0.5 inch and hornblende up to 0.2 inch. Its constituents, in descending order of abundance, are: Medium olive-gray feldspars, like those of the gray variety, slightly yellow-greenish smoky quartz, black hornblende and biotite (black mica), together with accessory magnetite, zircon, and allanite, and secondary kaolin, limonite, and calcite. The feldspar varies in the same particle from an olive green to a scarcely greenish milk-white. Limonitic stain is visible in the rift and other cracks of both feldspar and quartz. This stain seems to originate in particles of allanite and magnetite, in the biotite and hornblende, and partly in minute ferruginous particles in the feldspars not distinguishable from kaolin. Quarrymen state that this stone, which when first quarried is a dark gray, becomes greenish after an exposure of three to four hours to rain. It is also stated that the green granite loses some of its color on continued exposure about the quarry. Specimens of this slightly faded green granite show that, while the feldspars have lost a little of their greenness, that color is preserved in the quartz.

An estimate of the mineral percentages in this granite by the Rosiwal method yields the following results:

Estimated mineral percentages in Rockport green granite.

Feldspars	58.45
Quartz	31.95
Hornblende	9.60
	100.00

This granite takes as high a polish as the gray but its contrasts are less marked.

Besides these granites there is near Bay View a dark brownish-gray riebeckite-ægirite-biotite granite, which has only been prospected, and is described on page 139, and also near Pigeon Cove a beautiful diabase porphyry, which is as yet little worked. This is described on page 139. Finally there is the bright rust-colored "sap"

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referred to on page 57, which is unusually abundant in some of the Rockport quarries. This has been used by architects in the basements of several private residences on the Cape. The office of the Rockport Granite Company and the Rockport Carnegie Library are made of it. In both buildings the fresh gray granite has been used for trimmings. The resulting contrast is pleasing.

Geology of Rockport quarries.—The conspicuous feature of the Rockport quarries is the large number of basic dikes which traverse them. Some of these are shown in Pl. V, *A* and *B*. Their courses are given in the quarry descriptions. One attains a thickness of 18 feet. They are mostly diabase (soda-lime feldspar, augite more or less altered to hornblende, magnetite, and biotite). One was found to contain both augite and hornblende but no mica. The dike matter was erupted through deeply parted joints. Contemporaneous with them was the irregular-shaped injection described on page 50 and also shown in Pl. V, *B*. The faulting of the large dike in the same quarry shows that a crustal movement affected the region after the crystallization of the dike material. The injection of molten matter into cold granite was not without effect, for the stone on either side of these dikes is apt to be darkened. A thin section of this darkened granite from the Flat Ledge quarry (p. 127) shows it traversed by minute parallel or converging fractures, 0.004 to 0.04 inch apart. The intervening material is broken into angular slivers, and the walls of the fractures are coated with chlorite, and the adjacent feldspars are partly altered to mica. The darker shade of the granite is thus due to the secondary minerals, the formation of which was made possible by the cracking of the quartz and feldspar.

Segregations (knots) are not uncommon in Rockport granite, but at Halibut Point, the extreme north end of the Cape, in the Babson Farm quarry, there is one of unusual character. It is 8 by 4 by 2½ feet, and consists mainly of feldspar and quartz. The feldspar is a somewhat kaolinized light-grayish potash feldspar (microcline) minutely intergrown with soda-lime feldspar (oligoclase-talbie) and containing a few particles of quartz. The cleavage of the feldspar has in places a marked curvature. The quartz is amethystine smoky, in particles up to 2 feet across, and has cavities from 0.00285 to 0.0285 millimeter in diameter. In the center of this knot is a mass, 6 by 2 inches, of a yellow-brownish mineral of the augite group, which Mr. Johannsen determines as bronzite, a silicate of magnesia with 60 per cent of silica and 40 per cent of magnesia.

The pegmatite dikes contain some bright green feldspar (amazon stone). A 4-inch dike of aplite is bordered by pegmatite 1 to 2 inches thick.

Although some of the data obtained from the quarrymen as to rift and grain appear to be incorrect, owing to their confounding rift

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and grain or else to inaccurate observation, the course of the rift appears to be east-west and generally vertical and the grain horizontal. Rift and grain cracks can be detected in the quartz areas of polished surfaces.

Sheet structure is generally imperfect, owing either to the shortening of the lenses by increase in the curvature of the fractures or to the low-dipping joints which intersect them, or else to incomplete development. In some places the "toe-nail structure" enhances the difficulties.

The joints at the 11 quarries in operation have the following courses: About north, N. 25° E., N. 30°–40° E., N. 60°–75° E., about east-west, N. 15°–20° W., N. 30°–45° W., and N. 55°–70° W. The courses noted at the largest number of quarries were: N. 30°–40° E., N. 30°–40° W., N. 60°–75° E., and the east-west ones.

At the Upper Pigeon Hill quarry a compressive strain in all lateral directions results in undulating fractures and binds the chisels in channeling.

The Rockport quarries.—The Flat Ledge quarry is half a mile north-northwest of Rockport and 80 feet west of Sandy Bay. (See fig. 13.) Operator, Rockport Granite Company, Rockport, Mass.

The granite (specimens D, XXVIII, 24, a, f), "Rockport gray," is a hornblende granite of medium-gray shade with a slight bluish-green tinge and inconspicuous black spots. In large masses its general color is bluish gray. Its texture is medium to coarse, even grained, with feldspars up to 0.5 and hornblende to 0.2 inch. Its constituents, in descending order of abundance, are: A light-gray, slightly blue-greenish potash feldspar (orthoclase, some of it twinned, and microcline), minutely intergrown with soda-lime feldspar and somewhat kaolinized; very smoky quartz; black hornblende; and very little separate soda-lime feldspar (oligoclase-albite); together with accessory magnetite, molybdenite, purple fluorite, and zircon; and secondary kaolin and calcite.

Mr. George Steiger, chemist, of the United States Geological Survey, finds that it contains 0.20 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates the presence of 0.35 per cent of $CaCO_3$ (lime carbonate) calcite.

The stone takes a very high polish and hammers somewhat light.

The quarry, opened about 1855, measures about 1,100 feet from northwest to southeast by 1,000 feet across and from 45 to 120 feet in depth, but it is only worked in its northern part.

The sheets, from 6 inches to 30 feet thick, are horizontal in the southern part, dip 25° NW. on the east side, and in the center dip about 20° S. One set of joints, striking N. 15° W. and dipping 65° WSW., is spaced 8 to 15 feet. Another set, striking N. 60° W. and dipping 80° NNE., is spaced 2 to 25 feet. The rift is reported as

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A. UPPER QUARRY OF PIGEON HILL GRANITE COMPANY, ROCKPORT, MASS., LOOKING SOUTHWEST.

Showing thick granite sheets intersected by basic dikes. The black streaks in the front dike are underground water from sheet surfaces.

B. DEEP PIT QUARRY OF ROCKPORT GRANITE COMPANY, NEAR BAY VIEW, ON CAPE ANN, MASS., LOOKING NORTH.

Showing in upper part thick faulted dike of hornblende diabase, intersected by a thin dike of lamprophyre without biotite, reaching to bottom at left; also in center, below an irregular injection of hornblende diabase, joint planes, some of which are parallel to big dike.

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dipping 20° about S. and the grain as vertical with a N. 15°–20° E. course. A medium-grained pegmatite dike 5 feet thick, striking N. 30° W. and dipping 25° E., consists of potash feldspar (microcline and orthoclase), smoky quartz, soda-lime feldspar (oligoclase to andesine), garnet, and zircon. A coarse-grained dike, not examined microscopically, consists of a cream-colored feldspar, in places bright green, smoky quartz, black and possibly other varieties of mica, and garnets. Basic dikes strike N. 10° E., N. 15° W., and N. 60° W., dipping 40°, 70°, and 90°. The discolored granite adjacent to one of these was examined and has been described on page 125. Rusty stain, from one-fourth to 2 inches thick, is very abundant and bright, particularly along the joint faces. (See pp. 57, 125.)

The equipment of the quarry, combined with that of the adjoining "upper pit" quarry of same firm, will be found on page 128.

Transportation is effected by means of an 800-foot track to cutting shed and wharf.

The lower story of the Providence, R. I., post-office is made of stone from this quarry. Paving and crushed stone and riprap form a considerable part of the product, in tons, of the several quarries operated by this company. In 1905, 32,000 tons of paving blocks and 30,000 tons of riprap were produced, as against 50,000 of rough stone and 12,000 of dressed stone.

The "upper pit" of Rockport Granite Company lies west-southwest of the Flat Ledge quarry, about half a mile northwest of Rockport. (See fig. 13.) Operator, Rockport Granite Company, Rockport, Mass.

The granite, "Rockport gray," is a hornblende granite identical with that of the Flat Ledge quarry. (See p. 126.)

An estimate of the mineral percentages in this stone, made by the Rosiwal method, with half-inch mesh and total linear length of 20 inches, yielded the following results:

Estimated mineral percentages in Rockport gray granite from "upper pit" of Rockport Granite Company.

Feldspars	55.50
Quartz	38.90
Hornblende	5.60
	100.00

The quarry measures about 625 feet from northwest to southeast by 325 feet across, and averages 100 feet in depth, but there is an intermediate opening, 150 by 125 feet, averaging 40 feet in depth.

The sheets, from 4 to 35 feet thick, dip 20° about east. One set of joints strikes N. 30° E., dips 50° W., and is spaced down to 10 feet; another strikes about N. 30° W., dips 30°–50° E., and is spaced down to 5 feet. A third set, in the intermediate opening, strikes

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N. 70° E., dips steeply south-southeast, and is spaced 10 to 25 feet. A fourth set, "blind seams," strikes east-west, dips 50° S., recurs at very irregular intervals, and is not stained with limonite. The rift is reported as striking N. 80° W. and dipping 75°–80° S. The grain is probably like that in the Flat Ledge quarry. There are 4 basic dikes on the east and west sides striking N. 15° W. and dipping 70° E., and an 8-foot dike in the smaller opening striking N. 70° W. and dipping steeply north-northeast. A dike of aplite, 4 inches wide, with a border of pegmatite 1 to 2 inches thick with bright green feldspar, strikes N. 55° E. Gray knots measure up to 12 inches.

The combined plants of the "upper pit" and Flat Ledge quarry include 14 derricks, a hoisting engine, 7 large air drills, 25 air plug drills, and 6 steam pumps. Compressed air is furnished by the cutting plant on the wharf.

The cutting plants of the Rockport Granite Company are on the wharf near the Flat Ledge quarry and at Bay View near the other quarries of the company. They comprise 3 "stiff-legged" derricks, one of them with "bull wheel" and a three-drum engine, 3 locomotive cranes, 2 air compressors (capacity 1,400 and 350 cubic feet of air per minute), 10 air plug drills, 6 air hand tools, 6 surfacers, a McDonald surfacer for stones up to 8 feet wide, a set of 6 saws for blocks 20 feet long, 3 stone lathes (one for stones 30 by 3 feet, two for stones 12 feet by 20 inches), 3 polishing lathes for stones of above sizes, 6 vertical polishers, and 4 horizontal polishers; also a stone crusher with a capacity of 200 tons per day.

Transportation is effected by a track of 1,500 feet to wharf.

In 1906 this quarry was furnishing part of the granite for the piers and tower of the Cambridge-Boston bridge over the Charles River, and also for the anchorage of Manhattan Bridge No. 3 on the New York side.

The Pigeon Hill quarry ("lower quarry" of this company) is at the south foot of Pigeon Hill, one-third mile west of the shore and a mile north-northwest of Rockport. (See fig. 13.) Operator, Pigeon Hill Granite Company, Rockport, Mass.

The granite (specimens D, XXVIII, 34, a, b) is a hornblende granite of medium-gray shade with a slight bluish-green tinge and inconspicuous black spots. Its texture is medium to coarse and even grained. In texture, general color, and constituents this stone appears to be identical with that of the Flat Ledge and "upper pit" of the Rockport Granite Company. The only discernible difference is that the Pigeon Hill stone shows less quartz and a slightly lighter shade in the feldspar. The thin sections also show the presence along with the black hornblende of a little blue-black riebeckite (soda hornblende) and of a little biotite (black mica). Allanite, apatite, and pyrite appear also among the accessories. There is some sec-

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ondary brown hornblende filling microscopic cracks in the feldspar, also a little secondary hematite and limonite stain. Some cavities of irregular outline in the quartz measure up to 0.02 millimeter, others of oval or roundish form, with liquid and vacuoles, measure up to 0.0043 millimeter.

An estimate of the mineral percentages in this granite, made by the Rosiwal method, with half-inch mesh and a total linear length of 30 inches yields the following results:

Estimated mineral percentages in gray Rockport granite from the Pigeon Hill quarry.

Feldspars	58.86
Quartz	33.88
Hornblende	7.26
	100.00

A chemical analysis of this stone by H. S. Washington is given on page 123. Mr. E. C. Sullivan, chemist, of the United States Geological Survey, finds that it contains 0.14 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates a content of 0.25 per cent of $CaCO_3$ (lime carbonate), calcite.

The following data as to the compressive, compressed elastic, shearing, and transverse strengths of this granite were obtained by tests made at the United States arsenal at Watertown, Mass., in 1894 from stone quarried during the previous month:

Compressive strength.—Tests Nos. 6871, 6872, 6870, cubes about 4 inches square. First crack at 79,000, 86,000, 94,000 pounds. Ultimate compressive strength in pounds per square inch, 20,716, 20,522, and 17,772. Direction of rift and grain in cubes not given.

Compressed elastic strength.—The block tested measured 24 by 4.01 by 6.06 inches. Weight, 54.5 pounds. Weight per cubic foot, 161.5 pounds. Sectional area, 24.3 inches square. Pressure applied endwise. Under a pressure of 1,000 pounds per square inch the compression in a gauged length of 20 inches was 0.0031 inch. Under 2,000 pounds it ranged from 0.0063 to 0.0078 inch. Under 4,000 pounds it ranged from 0.0116 to 0.0129 inch. Under 6,000 pounds it ranged from 0.0162 to 0.0175 inch. Under 8,000 pounds it ranged from 0.0208 to 0.0209 inch. Under 10,000 pounds from 0.0253 to 0.0258 inch; and under 12,000 pounds it was 0.0297 inch.

Shearing strength.—Dimensions of block 12 by 6 by 4 inches, distance apart of supports 6 inches, width of plunger 5 inches. Tests Nos. 6879, 6880. First tension fractures midway between supports at 45,400 and 38,600 pounds. Shearing fractures developed later near edge of one support. Shearing strength 2,047 and 1,052 pounds per square inch of shearing area.

Transverse strength.—Dimensions of block, length 24, width 6, breadth 4 inches (decimals omitted). Length between end supports 19 inches. Tests Nos. 6882, 6883. Ultimate strength 12,320 and 12,480 pounds per square inch, equaling a modulus of rupture of 2,404 and 2,416, respectively. This was computed by the formula:

$$R=\frac{3\ p\ l}{2\ b\ d^2}$$

It takes a very high polish and hammers rather light.

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The quarry, opened about 1871, measures about 625 feet on the northeast side and 700 feet on the southwest side by 450 to 500 feet across and from 40 to 80 feet in depth.

The sheets, 6 to 10 feet thick, dip northeast about 10° in the northern part of the quarry, but 10° to 30° SE. in the southeastern part. The joint and dike courses are shown in fig. 14. Joints A dip 75° N., are spaced 3 to 10 feet, and abound in the southern part. Joints B dip 55° W., exceptionally 55° E., and are spaced 2 to 20 feet. In the southwestern part the closeness of these joints precludes the quarrying of large blocks. Joints C dip steeply west. The rift is reported as horizontal but feeble, and the grain as vertical with northwest course. Dike *a*, 10 to 12 inches thick, dipping 65° W. and forming the west side of quarry, is a fine-grained diabase consisting of soda-lime feldspar (andesine), hornblende from alteration of augite, magnetite, and black mica. Dike *b*, 18 inches thick,

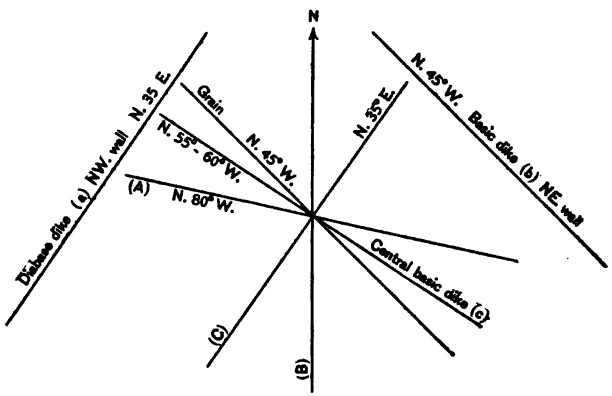

FIG. 14.—Structure at Pigeon Hill quarry, Rockport, Mass.

dipping 75° SW., forms the north wall; and dike *c*, 12 inches thick, dipping 75° WSW., crosses the center of quarry. Knots measure up to 10 by 7 inches and rusty stain up to 6 inches on sheet surfaces.

The plant consists of 3 derricks, a hoisting engine, a large air drill, 3 air plug drills, and a steam pump. The company's cutting plant, which receives material from both of its quarries, comprises 3 derricks, 3 hoisting engines, a locomotive crane, an air compressor (capacity 1,000 cubic feet of air per minute) which supplies both quarries, 5 surfacers, 2 air plug drills, 16 air hand tools, and a stone crusher with a capacity of 160 tons per day.

Transportation is effected by horsepower and an inclined track one-third mile long to wharf.

The product goes chiefly into buildings, but partly into paving and riprap for breakwater use. Specimen structures: The Charlestown, Mass., High School, entire; Bradford Memorial Chapel, at

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Gloucester, Mass.; The Chelsea, Mass., viaduct over Boston and Maine Railroad at Mystic Wharf. In 1906 this quarry was furnishing stone for the Union National Bank at Pittsburg.

The Upper Pigeon Hill quarry is about a mile northwest of Rockport, and one-third mile southwest of Pigeon Hill. (See fig. 13.) Operator, Pigeon Hill Granite Company, Rockport, Mass.

The granite is a hornblende granite of medium gray shade, with slight bluish-green tinge and inconspicuous black spots. Its texture is medium to coarse and even grained. It is identical in composition with the stone of the lower quarry of this firm described on page 128.

The quarry, opened about 1876, measures about 800 feet in a N. 35° E. direction by 450 feet N. 65° W., and from 50 to 100 feet in depth.

The sheets, from 4 inches to 12 feet thick, dip mainly west as high as 10°. Thin sheets are confined to the upper 20 feet. The sheet structure is generally regular, as shown in Pl. V, *A*. Joint and dike courses are given in fig. 15. Set A is vertical and spaced from 7 to 50 feet. Set B dips 20° south, and is spaced 50 feet. Its low inclination confuses the sheet structure in places. Set C dips 55° west, and is spaced 10 to 50 feet. Set D, exceptional and intermittent, dips 75° NE. Set E, also exceptional, dips 75° SSE. The rift is reported as vertical with N. 70° W. course and the grain as horizontal. There are 3 or more basic dikes from 12 to 18 inches thick: Dike *a* forms the northeast wall; dike *b*, about 350 feet from *a*, dips 80° northeast, and dike *c*, 300 feet southwest of *a*, is vertical. The intersection of the sheets by the central dike is well shown in Pl. V, *A*. Knots are reported as not over 2 feet, but rarely up to 10 by 5 feet. Rusty stain is from one-half inch to 12 inches thick.

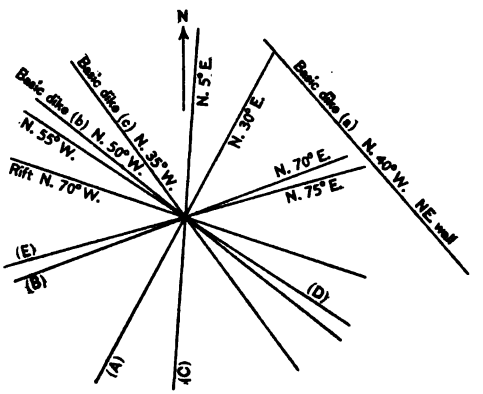

FIG. 15.—Structure at Upper Pigeon Hill quarry, Rockport, Mass.

The plant consists of 3 derricks, 3 hoisting engines, 3 large air rock drills, 5 air plug drills, and 3 steam pumps. The cutting plant has been given on page 130.

Transportation is effected by an inclined track of half a mile to the wharf.

The product is used largely in construction. In 1906 some of it was being used, under a subcontract, in the tower on the southeast corner of the Cambridge and Boston bridge over the Charles River.

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The Babson Farm quarry is at the north end of the cape, near Halibut Point, 2½ miles north-northwest of Rockport. (See fig. 13.) Operator, Rockport Granite Company, Rockport, Mass.

The granite (specimen D, XXVIII, 25, d) is a hornblende granite of somewhat dark greenish-gray shade. It is markedly darker than the granite of the Flat Ledge and Pigeon Hill quarries. Its texture is medium to coarse, even grained, with feldspars up to 0.5 inch and hornblende up to 0.3 inch. Its constituents, in descending order of abundance, are: Medium greenish-gray potash feldspar (orthoclase) intergrown with soda-lime feldspar, and in places much kaolinized; very smoky quartz with parallel sheets of cavities and abounding in prismatic grayish crystals up to 0.02 millimeter; black hornblende and very little separate soda-lime feldspar (oligoclase-albite). Accessory minerals are: Magnetite, zircon, and apatite. Secondary: Kaolin, limonite, hematite, and chlorite, the last in cracks and isolated particles within the feldspar, also along the boundaries of particles. To this mineral and to the limonite the feldspar owes its greenish tinge.

The quarry, opened about 1897, measures about 350 feet in a northeast direction by 150 feet across and from 40 to 50 feet in depth.

Sheet structure is normal. The sheets, from 4 inches to 15 feet thick, increasing in thickness downward, are horizontal or dip 10° NW. There are 4 sets of joints. Set A, striking N. 40° E., dipping 75° SE. or 90°, spaced 10 to 40 feet, forms the northwest and southeast walls. Set B, striking N. 40° W. and dipping 45°–50° SW., is spaced 100 to 200 feet. Set C, striking N. 65° W. and vertical, forms the northeast and southwest walls. Set D, striking N. 80° E., and vertical, forms a short heading near the north corner and recurs at rare intervals. The rift is reported as marked and vertical, with N. 50° E. course, and the grain as horizontal. A segregation of uncommon composition, measuring 8 by 4 by 2½ feet, from this quarry is described on page 125. There is some pyrite on the joint faces. Rusty stain from 1 to 6 inches thick occurs along the sheet surfaces.

The plant consists of 5 derricks, 3 hoisting engines, an air compressor (capacity, 550 cubic feet of air per minute), 2 large drills, 10 air plug drills, and 2 steam pumps.

Transportation is effected by cartage of one-fourth mile to wharf, which affords 30 feet of water at low tide.

No buildings constructed of this granite are reported.

The Breakwater quarry is on Folly Point, west of Folly Cove, 2½ miles northwest of Rockport. (See fig. 13.) Operator, Breakwater Construction and Engineering Company, 5 Nassau street, New York.

The granite is a gray hornblende granite, which, because of the use it was being put to, was not specially examined.

The quarry, opened in 1905, measures about 250 feet in a west-northwest direction by 100 feet across and from 5 to 30 feet in depth.

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Sheet structure is scarcely perceptible, but the intersecting joints and headings are so numerous as to facilitate quarrying for the purpose in view.

The plant consists of 8 traveling cranes of 10 to 20 tons capacity, an air compressor (capacity, 150 cubic feet of air per minute), 10 steam drills, 1 "stiff-legged derrick," and a rotary engine for loading onto barges.

Transportation is effected by a track of 300 feet to wharf.

The product is riprap for the Rockport breakwater, for the construction of a section of which, measuring 165 feet in length by 150 in width at low-water level, the company had a contract in 1906. The average weight of each block was to be 4,000 pounds and the minimum 200.

The Nickerson quarries are one-fourth mile southeast of Folly Cove, and 2 miles N. 30° W. of Rockport. (See fig. 13.) Operator, W. E. Nickerson, Lanesville, Mass.

The granite, like specimen D, XXVIII, 29, a, from the Devils Rock quarry, described on page 134, is a hornblende granite of medium-gray shade with a slight buff tinge and weak contrasts.

The main quarry, opened in 1896, is triangular, measuring about 350 feet N. 40° W. by 350 feet E. and 400 feet N. 40° E., and up to 25 feet in depth. The other opening measures about 100 by 60 feet and 60 feet in depth.

The sheets from 9 inches to 6 feet thick undulate horizontally. There are 4 sets of joints: Set A, striking nearly east-west and vertical, is spaced 10 to 100 feet. Set B, striking N. 40° E., occurs but exceptionally. Set C, in the smaller pit, striking north and vertical, is spaced 10 to 20 feet. Set D, in the smaller pit, striking N. 30° W. and dipping 70° E., is spaced from 10 feet up. The rift is reported as vertical with east-west course and the grain as horizontal. A vertical diabase dike 6 feet thick, weathering spheroidally, strikes N. 40° W. and forms the northeast wall of the main quarry near the smaller one. Another east of the quarry has a like course. Knots are reported as not exceeding 1 foot in diameter. Rusty stain is 2 inches thick on lower sheets and 9 on the upper ones.

The plant consists of 4 derricks, 3 hoisting engines, a steam drill, and 3 steam pumps.

Transportation involves cartage of one-half mile to Lanesville wharf.

The product consists largely of paving stone, with some "random" stone, and finds a market mostly through the Rockport Granite Company.

The Canney quarry is on the east side of Lanesville, about 2 miles N. 50° W. from Rockport. (See fig. 13.) Operator, Edwin Canney, Pigeon Cove, Mass.

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The granite is a hornblende granite of medium gray, not bluish, shade and of medium texture, like that of the "deep pit" of the Rockport Granite Company. (See p. 137.)

The quarry, opened about 1861, measures about 500 feet in a N. 40° E. direction by 400 feet across, and averages 65 feet in depth.

The sheets, from 6 inches to 25 feet thick, increasing in thickness downward, dip about 10° in a general S. 45° W. direction. Joints, striking N. 60° E. and vertical, are spaced 3 to 30 feet. The rift is reported as vertical with N. 25° E. course and the grain as horizontal. Three vertical basic dikes, from 18 to 24 inches thick, strike N. 40° W. One forms the west wall; another is 100 feet east of it, and another 75 feet east of that. Knots up to 5 inches are reported.

The plant consists of 5 derricks, 3 hoisting engines, an air compressor (capacity 470 cubic feet of air per minute), 4 steam pumps, and a stone crusher with a capacity of 100 tons per day.

Transportation is effected by an inclined track of 2,500 feet to wharf when water is smooth, but by cartage to Lanes Cove in rough weather.

The product is mostly paving, with some curbing, flagging, crushed stone, and foundation stones. It goes to Boston, New York, and Philadelphia.

The Devils Rock quarry is about half a mile southeast of Lanesville and about 1¾ miles N. 58° W. of Rockport. (See fig. 13.) Operator, William R. Cheves, Lanesville, Mass.

The granite (specimen D, XXVIII, 29, a) is a hornblende granite of general medium gray, not bluish, shade and of medium to coarse, even-grained texture, with feldspars up to 0.4 inch and black hornblende up to 0.3 inch. It consists, in descending order of abundance, of: Light-gray potash feldspar (microcline and orthoclase), from slightly greenish to cream-colored, minutely intergrown with soda-lime feldspar (albite to oligoclase-albite) and somewhat kaolinized; very smoky quartz with cavities; and black hornblende. Accessory: Magnetite, pyrite, zircon, and allanite. Secondary: Kaolin.

The quarry, opened in 1876, measures about 400 by 200 feet and averages about 50 feet in depth.

The sheets, from 1 to 18 feet thick, dip 10° N. There are 3 sets of joints. Set A, striking N. 25° E., dipping 70° E. to 90°, is spaced 3 to 90 feet and forms a heading on the west side. Set B, striking N. 70° W. and dipping 45° to steeply north, is spaced from 1 to 50 and 100 feet and forms a heading on the south side and the wall on the north. Set C, diagonal, striking N. 25° E. and dipping about 65° NW., is spaced 20 feet at the south end, but does not recur. The rift is reported as good, vertical, and with east-west course. There is a 6-inch basic dike on the east side. Gray knots are reported up to 14 by 6 inches. Rusty stain is from 1 to 6 inches thick.

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The plant, including that at the green granite quarry of the same firm, comprises 9 derricks, 2 hoisting engines, an air compressor (capacity 560 cubic feet of air per minute), 2 steam drills, 6 air plug drills, and 3 steam pumps.

Transportation involves cartage of a mile to Lanesville wharf, which affords 13 feet of water at high tide.

The product is used for building and paving. In 1906 this firm had a subcontract for material for the naval dry dock at Kittery, Me.

The Cheves Green Granite quarry is about 250 feet south of the Devils Rock quarry and 1¾ miles N. 60° W. from Rockport. (See fig. 13.) Operator, William R. Cheves, Lanesville, Mass.

The granite (specimen D, XXVIII, 30, a), "green granite," is a hornblende granite of somewhat dark olive-gray color, spotted with black, and of medium to coarse even-grained texture, with feldspars up to 0.5 inch and hornblende up to 0.3 inch. When first quarried the yellowish-green tint is scarcely perceptible, but after a few hours exposure to rain it becomes marked. Its constituents, in descending order of abundance, are: A medium olive-gray potash feldspar (orthoclase and microcline, much of it twinned), minutely intergrown with soda-lime feldspar (many of the feldspars are much kaolinized and contain minute particles, possibly of an oxide of iron); very smoky quartz with cavities and black particles; some separate soda-lime feldspar (albite to oligoclase-albite); and black hornblende. Accessory: Magnetite, allanite (most of it within hornblende particles), and zircon. Secondary: Calcite, and limonite stain, some of it proceeding radially from allanite particles, also in cracks and along boundaries of particles.

The contrast in this stone, owing to the dark shade of the quartz, is mostly between the feldspar and the combined quartz and hornblende.

The quarry is somewhat triangular in outline, measuring about 200 feet N. 70° W. by 100 to 200 feet across and from 30 to 90 feet in depth.

The sheets are up to 35 feet thick. The joints correspond to sets A and B of the Devil's Rock quarry, and the rift is said to be like the rift of that quarry, but less marked.

The Blood Ledge quarry is three-fifths mile east-northeast of Bay View and 2 miles N. 62° W. of Rockport. (See fig. 13.) Operator, Rockport Granite Company, Rockport, Mass.

The granite (specimens D, XXVIII, 28, b, e), "Bay View green," is a hornblende granite of general somewhat dark olive-gray color, with black spots, and of medium to coarse, even-grained texture, with feldspar up to 0.5 inch and hornblende up to 0.2 inch. Its constituents, in descending order of abundance, are: A more or less kaolinized medium olive-gray potash feldspar (orthoclase and micro-

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cline, mostly twinned), minutely intergrown with soda-lime feldspar (albite to oligoclase-albite); very smoky quartz with cavities and black particles; black hornblende; and rarely a little biotite. Accessory: Magnetite, allanite, zircon. Secondary: Kaolin, chlorite, and limonite stain. This stain occurs in meandering cracks in both feldspar and quartz, and along the boundaries of particles, and also radiates from allanite particles, which are one of the primary causes of the yellowish-green tint of the granite. Part of this quarry yields a gray granite like that of the "Deep Pit" (p. 137) and part a granite of a darker gray which, however, after wetting, becomes, in three to four hours, olive green, the "green granite" described above. After continued exposure about the quarry the green tint is said to become less marked.

An estimate of the mineral percentages in this stone, obtained by the Rosiwal method, with a mesh of seven-tenths inch and a total linear length of 16.8 inches, yields the following results:

Estimated mineral percentages in "green granite" from Blood Ledge quarry, Rockport, Mass.

Feldspar	58.45
Quartz	31.95
Hornblende	9.60
	100.00

This stone takes a very high polish and hammers rather light. Some particles of feldspar vary on the polished face from an olive green to a scarcely greenish milk white. The contrasts between the three minerals are more marked on the polished face. This granite is well adapted for indoor decorative use.

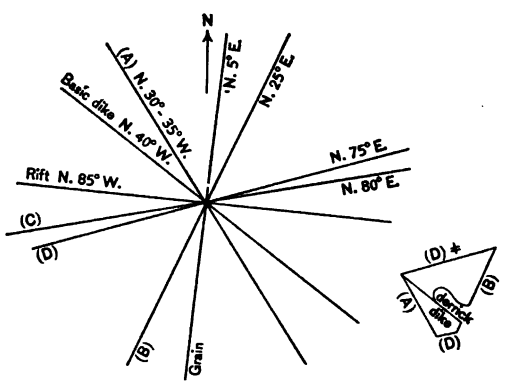

FIG. 16.—Structure and plan of Blood Ledge quarry, Rockport, Mass.

The quarry, opened about 1868, forms an inequilateral quadrangle, the longest side of which measures about 400 feet, and which is bisected by a basic dike and contains an unexcavated central mass upon which the derrick stands, as shown in fig. 16. Its depth ranges from 28 to 100 feet below the general surface, from which, however, 50 feet had already been quarried away.

The sheets, 10 to 30 feet thick, dip 15° west. There are 5 sets of joints, whose courses are given in fig. 16: Set A, dipping 55° east, is spaced 3 to 30 feet and forms the west wall. Set B, exceptional,

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dips 50° west. Set C dips 30° north. Set D, dipping 90° or steeply south, forms the short south wall and recurs intersecting the north wall. The rift is reported as vertical with a N. 85° W. course, and the grain as also vertical and about north-south. The stone is said to split most readily from the ends of the blocks, both along rift and grain. The basic dike, shown in fig. 16, is 2 feet thick and dips 70° southwest. Dark knots a few inches in diameter were collected, but they are reported as occurring up to the size of half a barrel. Rusty stain is up to 3 inches thick on sheet faces.

The plant consists of 6 derricks, 4 hoisting engines, 3 steam drills, and 2 steam pumps.

Transportation is effected by a locomotive (p. 139) and track about 1 mile long to the wharf at Bay View.

The product is used for buildings, monuments, docks, and paving. Specimen structures: Of gray granite, the first story (outside) of Suffolk County court-house, Boston. Six polished columns and two pilasters in the Madison Square Presbyterian Church, New York. Of green granite, the base of the General Logan monument in Chicago.

The "Deep Pit" is about one-fifth mile from tidewater at Bay View, on the west side of the Cape, 2¼ miles N. 73° W. of Rockport. (See fig. 13.) Operator, Rockport Granite Company, Rockport, Mass.

The granite (specimens D, XXVIII, 27, a, b), "Bay View gray," is a hornblende granite of medium-gray shade (lighter than 25, d, Babson quarry, p. 132, and darker than 24, a, 34, a, and 29, a, Flat Ledge, Pigeon Hill, and Cheves quarries, pp. 126, 128, 134), with a slight cream and greenish tinge, spotted with black. Its texture is medium even grained, with feldspars up to 0.4 and hornblende up to 0.3 inch. Its constituents, in descending order of abundance, are a cream-colored and pale-greenish, more or less kaolinized potash feldspar (orthoclase and microcline, mostly twinned) minutely intergrown with soda-lime feldspar; very smoky quartz with cavities; a little separate soda-lime feldspar (oligoclase-albite), and black hornblende. Accessory: Magnetite, zircon, and allanite. Secondary: Kaolin, chlorite, calcite, and hematite and limonite stain. The colors of feldspar are evidently due to the chlorite and limonite.

An estimate of the mineral percentages in this granite, by the Rosiwal method, with half-inch mesh and total linear length of 20 inches, yields the following results:

Estimated mineral percentages in Bay View gray granite, Rockport, Mass.

Feldspar	59.60
Quartz	34.70
Hornblende	5.70
	100.00

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This granite takes a very high polish. In the rough its contrasts are less marked than those of the Flat Ledge and Pigeon Hill stone, and the color of the feldspar is different, but the contrasts are more marked on the polished face owing to the lighter shade of the feldspar.

The quarry, opened about 1848, measures about 800 feet N. 20° W. by 500 feet across, but owing to a recess its actual area is about 750 by 500 feet. Its depth is from 60 to 150 feet. A diagonal view of this quarry is given in Pl. V, *B*, and a rough plan of it in fig. 17.

The sheet structure is hardly perceptible, but at the south end seems to dip 20° E., and at the northeast corner to undulate horizontally. In the absence of sheets horizontal channeling has to be resorted to. Steeply downward curving partings, "toe nails," are conspicuous in the central part. Joint and dike courses are shown in fig. 17.

There are 5 sets of joints: Set A is vertical. Set B dips 60° E. Set C dips 55° northeast. Set D is vertical. The rift is reported as vertical with N. 85° W. course, and the grain as horizontal. The stone is said to split readily from the top. There are 5 basic dikes. The central one, *a*, of hornblende diabase (soda-lime feldspar—andesine—micacized, augite, hornblende, magnetite, and black mica—biotite), from 12 to 18 feet thick, and dipping 55°–60° NE., crosses the quarry diagonally, but with marked curvature, from N. 20°–45° W., and is also faulted along dike *b* with a lateral displacement of about 15 feet. Both of these dikes and the fault are shown in Pl. V, *B*. Dike *b*, a lamprophyre without biotite (soda-lime feldspar—andesine—altered to white mica, zoisite, and epidote, also with hornblende, augite, and magnetite) is 18 inches thick and dips 55° WNW. Dikes *c*, *d*, and *e* are vertical. In the northern part a small branching and curved basic dike intersects and branches off from dike *a*. The relations of these dikes are shown in fig. 17. In about the center of the quarry at a depth of 125 feet is an irregular mass of injected hornblende diabase, more fully described on page 50, and also shown in Pl. V, *B*, and fig. 2, which is probably connected more or less remotely with dike *a*. Rusty stain along sheet surfaces measures up to 6 inches in thickness.

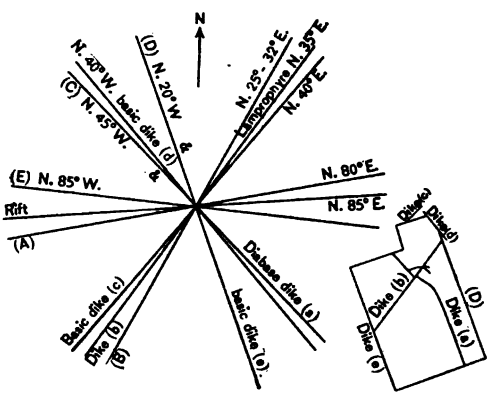

FIG. 17.—Structure and plan of Deep Pit quarry, near Bay View, Mass.

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The plant comprises 4 derricks, 4 hoisting engines, a Blondin carrier, a locomotive, an air compressor (capacity 1,750 cubic feet of air per minute), which supplies this and the Blood Ledge quarry, 2 steam drills, and 2 steam pumps.

Transportation is effected by a half-mile track to the wharf at Bay View, which affords 15½ feet of water at low tide.

Specimen structures: The Boston and Baltimore post-offices.

The Bay View dark-granite prospect is between the Blood Ledge quarry and the "Deep Pit" near Bay View, and was opened by the Rockport Granite Company, of Rockport, Mass. It may be in the small area of augite syenite shown on Sears's geologic map of Essex County.[a]

The granite (specimens D., XXVIII, 28½, a, b) is a riebeckite-ægirite-biotite granite of dark brownish gray color and medium to coarse, even-grained texture, with feldspars up to 0.5 inch in diameter. It consists, in descending order of abundance, of a brownish gray potash feldspar (orthoclase and microcline), somewhat kaolinized, mostly in twins and minutely intergrown with soda-lime feldspar; slightly smoky quartz; brownish gray soda-lime feldspar (albite to oligoclase-albite); blue-black riebeckite (soda-hornblende) and green-black ægirite (soda-augite), and black mica. The accessory minerals are: Magnetite, allanite, zircon, fluorite, and apatite; the first three are somewhat abundant. Secondary calcite is present in small amount and a little limonite stain occurs to which the feldspars owe their brownish tinge. They also contain minute particles of all the black silicates.

This rock takes a very high polish and hammers rather light. The quartz and feldspar being of about one shade, the only contrast on the polished face is between these and the black silicates. On the rough face the contrast is slight.

Rockport porphyry.—The Pigeon Cove diabase porphyry prospect is on a dike of altered diabase porphyry, 18 feet wide, which was represented by Shaler[b] and Tarr as exposed for half a mile on the hillock west of Pigeon Cove, with a N. 21° W. course, also as reappearing in Rockport three-fourths mile west of Gap Head with a N. 9° W. course. Washington[c] refers to this dike as cutting the quarry pit at Pigeon Cove, and describes it microscopically as a labradorite porphyry.

Fuller, Foley & Co., of West Quincy, Mass., have quarried a few carloads of this rock and have made a polished ball of it, 2 feet 7 inches in diameter, mounted on a cubical base. Fig. 18 was prepared from a photograph of it taken by the writer.

This diabase porphyry (specimens D, XXIX, 89, a, b) has a very dark green or black fine-grained groundmass, with porphyritic feld-

[a] Sears, J. H., The physical geography, geology, mineralogy, and paleontology of Essex County, Mass., Essex Institute, Salem, Mass., 1905.

[b] Shaler, N. S., The geology of Cape Ann, Mass.: Ninth Ann. Rept. U. S. Geol. Survey, 1889, p. 609, Pl. 77.

[c] Washington, H. S., The petrographical province of Essex County, Mass.: Jour. Geol., vol. 7 (3) p. 290.

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spars of medium greenish gray color, measuring from 0.2 to 4.42 inches in length by about 0.78 inch in width. Many of the crystals are from 1 to 2 inches long. Their striation shows plainly. Fig. 18 shows the general character of the rock. The groundmass consists of the following minerals, in descending order of abundance: Lime-soda feldspar (andesine-labradorite) partly micacized, augite largely altered to a green hornblende and chlorite, biotite (black mica), magnetite, and apatite. Rarely a little secondary calcite.

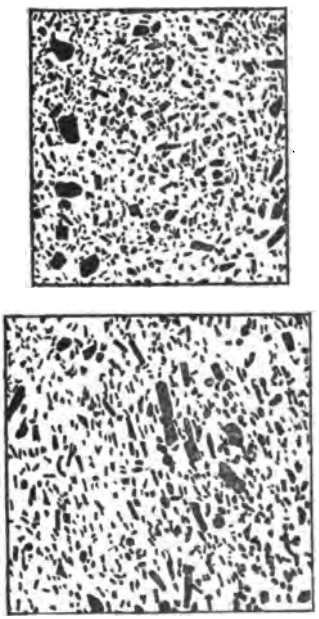

FIG. 18.—Labradorite feldspars in polished surfaces of diabase porphyry from the dike at Pigeon Cove on Cape Ann, Mass., one-thirteenth natural size. The largest crystal is 4.4 inches long.

This rock takes a very high polish and the contrast between the black groundmass and the large pale-greenish crystals is most striking.

BECKET (CHESTER).

Topography.—The town of Becket is on the southern continuation of the Green Mountain range in the east-central part of Berkshire County, Mass. The range attains thereabouts elevations of 1,750 and 1,845 feet, but is deeply cut by south-southeasterly valleys, through which flow the branches of Westfield River, and by minor north-south and east-west hollows tributary to those valleys.

General geology.—The geology of the region has been described by Emerson,[a] and will appear in a revised form in the forthcoming Housatonic folio of the United States Geological Survey. There is a long north-south area of so-called Becket gneiss, which is of pre-Cambrian age. In some places, as at the quarry, to be described, it is a true granite, which has undergone only a very slight textural change. East of it lies a belt of marine sediments, now called Ordovician by Emerson, once clayey but afterwards metamorphosed into mica schist. The granite at the quarry contains a large inclusion of somewhat coarse muscovite-biotite garnetiferous gneiss. It is also overlain by or incloses a considerable mass of a black schistose quartz-mica diorite, containing both potash and soda-lime feldspar, along the contact with which the granite has a banded flow structure. It is, therefore, evident that the granite of Becket is more recent than these two rocks; in other words there were gneisses (probably of granitic origin) and schists (originally quartz-mica

[a] Emerson, B. K., Geology of eastern Berkshire County, Mass: Bull. U. S. Geol. Survey No. 159, 1899, Pl. IX, pp. 75, 99.

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diorite) in this region before the intrusion of the Becket granite. The diorite schist once overlay the surface of the granite and, either alone or with other rocks, possessed a considerable thickness. The granite of the Becket quarry has been described by Kemp and Emerson.[a]

The quarry.—The Hudson and Chester Granite quarry is in the town of Becket, 1,400 feet above sea level, 6¾ miles southeast of Becket village, in Berkshire County, Mass., and 2¾ miles (3½ by road) southwest of the village of Chester, on the Boston and Albany Railroad, in the town of Chester in Hampden County. (See the Becket, Chesterfield and Housatonic topographic sheets of the Geological Survey.) Operator, Hudson & Chester Granite Company, Chester, Mass.

The granite (specimens D, XXIX, 91, f, g, k), "Chester dark" and "Chester light," is a muscovite-biotite granite of medium inclining to dark bluish gray, to medium bluish gray color and of fine texture with feldspars up to 0.15 inch and mica in very fine particles. The texture of this granite is neither exactly gneissoid, porphyritic, nor even grained. In thin section the coarser particles of quartz and feldspar are seen to lie in a somewhat micaceous matrix of very fine texture, and there is not a little granulation about the feldspars. The average diameter of the particles of this matrix, estimated by the Rosiwal method, is less than 0.005 inch, which is finer than the finest Westerly granite (p. 192), although the stone as a whole is coarser textured than that. Its constituents, in descending order of abundance, are: Light bluish-gray potash feldspar (microcline, rarely orthoclase); slightly bluish quartz, with sheets of cavities (up to 0.02 millimeter in diameter) in two rectangular directions with brightly polarizing rift and grain cracks parallel to them; light bluish gray soda-lime feldspar (oligoclase-albite); white mica (muscovite); and black mica (biotite). The only difference between the dark and light varieties is in the percentage of the black mica. The accessory minerals are: Titanite, pyrite, ilmenite, allanite, fluorite, apatite, and zircon. The secondary: Muscovite, carbonate, and epidote (as rim about allanite). The amount of titanite is relatively large.

An estimate of the mineral percentages in this granite, by the application of the Rosiwal method to a camera lucida drawing of a thin section enlarged 37 diameters, with a mesh of 1.2 inch and a total linear length of 25.85 inches, yields the following results:

Estimated mineral percentages in Becket, Mass., granite.

Quartz	49.35
Potash feldspar (orthoclase 17.05, microcline 11.50)	28.55
Soda-lime feldspar (oligoclase-albite)	15.37
Mica (muscovite, 4.10, biotite, 2.47)	6.57
Titanite	.16
	100.00

[a] Kemp, J. F., On the granite quarried at Chester, Mass.: Trans. N. Y. Acad. Sci. vol. 11, 1891–2, pp. 129–130. Emerson, B. K., Geology of Old Hampden County, Mass.: Mon. U. S. Geol. Survey, vol. 29, 1898, pp. 33, 34, 36–38; and Bulletin No. 150, pp. 75, 99.

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The following analysis, by Prof. L. M. Dennis of Cornell University, is quoted by Kemp.[a]

Analysis of Becket, Mass., granite.

SiO_2 (silica)	69.465
Al_2O_3 (alumina)	17.50
Fe_2O_3 (iron sesquioxide)	2.30
CaO (lime)	2.57
MgO (magnesia)	.305
K_2O (potash)	4.07
Na_2O (soda by difference)	2.93
H_2O (water at 110°)	.08
Loss on ignition	.74
	99.960

Specific gravity 2.684 to 2.688.

Mr. George Steiger, chemist of the United States Geological Survey, finds that this granite contains 0.53 per cent of CaO (lime), soluble in hot dilute acetic acid, which indicates a content of 0.94 per cent of $CaCO_3$ (lime carbonate), the presence of which carbonate is also shown by the microscope and by a slight effervescence with cold dilute muriatic acid.

Professor Kemp[a] states that a cube of this stone was tested at Columbia University by boiling in dilute muriatic acid (1 part of HCl of specific gravity 1.20 to 20 parts of H_2O) for 5 hours, when it was found to have lost 0.59 per cent in weight. Another boiled for the same length of time in dilute sulphuric acid (1 part of H_2SO_4 of specific gravity 1.84 to 20 parts of H_2O) gave a loss of 0.48 per cent.

Absorption and crushing tests, made at the same time and place, yielded the following results: Four cubes of specific gravities, 2.688, 2.687, 2.684, and 2.688, after 3 weeks' soaking, absorbed 0.0021, 0.0021, 0.00224 and 0.0026 per cent. The crushing test was applied to five cubes, which showed a crushing strength per square inch ranging from 25,350 to 28,841 pounds.

The stone takes a fair polish and hammers somewhat light. The fineness of the particles precludes any marked contrast. Feldspar and quartz appear light gray, and the mica, black, producing a fine mottling.

The quarry, opened in 1886, measures about 600 feet east-west by 100 feet across and from 50 to 100 in depth.

The sheets are normal lenticular and horizontal, becoming thicker downward and measuring 6 inches to 30 feet in thickness, but there is some irregularity in this increase in different parts of the quarry. There are two sets of joints. Those of set A strike N. 10° E., dip 30° to 35° W., and are spaced from 18 inches to 20 feet. They are intermittent and have a thin coat of discoloration, the microscopic character of which is described on page 61. Those of set B strike N. 80°

[a] Loc. cit.

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W., are vertical, and are spaced 10 to 25 feet, exceptionally curved so as to dip as low as 55° W. On the north side a mass of fine-grained, heavy, hard, black schist, 40 feet thick, overlies the granite. It is traversed by horizontal and vertical quartz veins, the latter taking their rise at the contact with granite and tapering upward. Emerson[a] represents this mass as also overlain by the granite at one end, but that part had probably been quarried away before the writer's visit in 1906. A thin section of this rock, crossing also a tortuous white veinlet, is found to consist, in descending order of abundance, of: Quartz, with sheets of cavities and rift cracks parallel to them polarizing brightly; black mica; potash feldspar (microcline); soda-lime feldspar (oligoclase); muscovite, and hornblende. The accessory minerals are: Ilmenite, titanite, pyrite, apatite, and zircon. The secondary: Epidote, carbonate, and limonite. The white veinlets are mainly quartz and soda-lime feldspar. This rock thus appears to be a quartz-mica diorite schist, but with potash feldspar apparently exceeding the soda-lime. It is an eruptive rock made schistose by pressure before the intrusion of the granite, and probably formed part of the original cover into which granite was intruded. That the granite is the later rock is evident because of the marked flow structure which, for a space of 2 feet below the diorite schist, runs parallel to the contact surface, as has been observed in some New Hampshire quarries (p. 62). This flow structure consists of parallel white bands from 0.1 to 0.3 inch wide, recurring at intervals of 1 inch. The gray granite between these light bands is darker than that beyond them. A thin section of one of these bands shows it to consist of quartz and feldspar, the quartz with many sheets of cavities up to 0.03 inch, and with rift cracks parallel to them. In the darker bands biotite, epidote, titanite, and muscovite are very abundant. At the northeast corner the flowage bands have very sinuous courses, the rock taking on the appearance of a true gneiss. On the west side the flow structure, shown by a band of lighter granite 2 feet thick, strikes N. 55° E., and dips 40° SE. At the northwest corner, several feet below the granite surface, is an inclusion, 10 by 8 feet, of coarse garnetiferous muscovite-biotite gneiss with accessory magnetite, apatite, and zircon. It is a very different rock from either the granite or the diorite schist, and was evidently broken off from some overlying or adjacent formation during the granite intrusion and inclosed by the molten matter.

The rift is reported as dipping about 20° W. and the grain as vertical with a N. 10° E. course.

At the northwest corner there is a pegmatite dike (feldspar and quartz, coarse) up to 2 feet thick, with a northwest course. In thin section the feldspar is orthoclase with fissures from 0.37 to 1.85

[a] Bull. U. S. Geol. Survey No. 150, fig. 16, p. 75.

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millimeters wide, filled with fragments of microcline and quartz and stringers of white mica. It has evidently been subjected to pressure and some metamorphism.

Rusty stain along the sheet surfaces is from 3 to 12 inches thick.

The plant, including the cutting machinery at Chester, comprises 7 derricks, 6 hoisting engines, a Blondin carrier and engine, 2 overhead cranes (capacity 4 tons), 2 air compressors (capacity 500 and 150 cubic feet of air per minute), 4 large drills, 14 air plug drills, 8 air hand tools, a surfacer, 4 vertical polishers, and a steam pump.

Transportation is effected by the Chester and Becket Railroad, a branch of the Boston and Albany, which connects the quarry through Walker Brook hollow with the main line at Chester, a distance of 3½ miles. The rough stone is shipped direct from the quarry; the rest is taken to the cutting shed at Chester and reshipped there. The granite thus comes to be known as Chester granite although the quarry is in Becket.

The product is used mostly for monuments and finds its chief markets in Pennsylvania, New York, and Michigan. Specimens: Doctor Hoover monument at Chambersburg, and the McCormack monument at Pittsburg, Pa., and the W. A. Harder monument at Hudson, N. Y.

NEW HAMPSHIRE.

GENERAL STATEMENT.

Some of the New Hampshire granite quarries to be described are near Concord, in Merrimac County, and Milford, in Hillsboro County, which are both in the Merrimac River basin in the southern part of the State. The rest are near Conway, on the south side of the White Mountain region, in the east-central part of the State. (See map, Pl. I.) The Concord and Milford quarries are in an area designated by Prof. C. H. Hitchcock "Lake Winnepesaukee gneiss," which on his geological map has a northeast to southwest trend, and is dovetailed both on the northeast and the southwest into a schist formation designated "Rockingham schists," which he regarded as forming the base of the Cambrian. Both the Concord and the Milford granite carry inclusions of gneiss, but the relations of these to the Rockingham schists is as yet undetermined. Some gneisses which cap the Milford granite are evidently of igneous origin, so can not be the Rockingham schists. The Conway quarries are in an area of granite designated on the same map "Conway granite," which measures about 35 by 20 miles and extends from the Franconia Mountains on the west to Conway on the east, and from the foot of Mount Washington on the north to Mount Chocorua on the south.[a]

[a] See Hitchcock, C. H., The geology of New Hampshire, Concord, 1878, Atlas. Also The geology of northern New England, printed by the author, apparently between 1885 and 1892. New Hampshire map is dated 1877.

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The Auburn and Sunapee quarries were not visited, but the granite from these localities will be found described on pages 186, 187.

CONCORD.

Topography.—The Concord quarries are on the east side and top of a north-south ridge known as Rattlesnake Hill, which is said to attain an elevation of 580 feet above the high-water mark of Merrimac River; and they lie within a radius of 1½ to 2 miles from about N. 25° W. to N. 50° W. of the statehouse. Some of them are at the foot of the ridge on North State street at about the level of the city; others are from 70 to 360 feet above it.

Geology of the quarries.—The salient geological feature is the occurrence here and there within the granite of inclusions of coarse and fine banded gneisses measuring from a few inches to 30 feet in diameter. The largest of these (see page 153) is a bright, dark biotite-muscovite gneiss with fine bands of varying shades, according to the proportions of the micas or of the quartz and feldspar. Its feldspar is a soda-lime (oligoclase-albite to oligoclase), and the accessory minerals are garnet, zircon, apatite, etc. Others again are biotite gneisses and consist of alternating bands of very light feldspathic quartzose rock and of dark, coarse, very fine micaceous schist, the particles of the latter not exceeding 0.02 inch. The geological age of these gneisses is uncertain. The pegmatite dike which traverses this large inclusion seems, from its relation to the granite, to have been formed before the block was surrounded by granite. Of general interest is also the occurrence of fluorite on joint faces, referred to on page 61, which implies deep-seated origin of the solutions out of which it crystallized, and raises the question as to whether the associated calcite and quartz may not have come from the same source.

Joint planes at the Concord quarries divide themselves into 8 sets, of which those occurring at the largest number of quarries strike N. 15° E., N. 20°–30° E., N. 60°–65° E., and N. 60°–75° W. Of less frequent occurrence are those striking N. 10° W., N. 45° W., N. 80° E. and E.-W. The number and variety of fractures within one of the headings at the Granite Railway quarry indicate the localization and sharpness of the strain which produced the heading.

Flow structure appears at only one quarry, where it is vertical with a N. 60° W. course. The rift is reported as either horizontal or inclined from 5° to 15° (N. 65°, 75° W., S. 45° W.), and the grain as vertical with east-west course, but exceptionally N. 45° E., N. 70° E., N. 80° W. The effect of heat and cold on the quality of rift and grain is recognized, and also the fact that the degree of dip of rift is affected by the direction in which the sheet is split. If the splitting is done from the north or south the rift will prove horizontal, but if

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from the west it will be inclined. Whether the east-west compressive strain which affects Rattlesnake Hill has anything to do with this deflection is uncertain.

There are pegmatite dikes with courses of N. 30° E., N. 45° E., N. 45° W., and N. 85° W. and segregations of very fine porphyritic granite. (See p. 155.)

Description of Concord granite.—The following combines all the more detailed descriptions of rough and polished specimens and thin sections given on pages 147–156.

"Concord granite" is a muscovite-biotite granite of medium bluish gray color. The significance of the term "medium gray" becomes apparent upon comparing the terms applied to the principal light granites of New England. Hallowell, Me., granite is *light gray;* the "white granite" of North Jay, Me., is *very light gray;* and the granite of Bethel, Vt., is *white mottled with gray.* The general shades of these light or whitish granites forms a descending series in which Concord granite stands fourth, the granite of Bethel, Vt., being the lightest. The texture of Concord granite is fine to medium, somewhat porphyritic, with sparse, slender, isolated feldspars up to 0.5 inch. Although the micas occur in very minute particles, especially the biotite, they measure up to 0.2 inch and exceptionally 0.4 inch. Its constituents, in descending order of abundance, are: Slightly bluish, translucent potash feldspar (microcline, usually in longish twins, and some orthoclase), inclosing particles of quartz and of soda-lime feldspar (in some specimens these minerals with biotite are zonally arranged within a crystal of feldspar); clear to pale amethystine quartz with hairlike crystals, probably of rutile, and with cavities in sheets which in some sections are parallel; milk-white, striated soda-lime feldspar (oligoclase-albite) more or less kaolinized and centrally micacized; white potash mica (muscovite); and black mica (biotite) some of it chloritized, generally in smaller scales than the muscovite. In some cases the mica plates have their flat sides parallel to the rift direction; in some the biotite appears to predominate over the muscovite, possibly owing to the different alignment of its scales. The accessory minerals are: Magnetite, apatite, zircon (some in doubly terminated slender prisms), and rutile. Purple and white fluorite occurs here and there on and near joint planes. Calcite and quartz are associated with it on these joints. The secondary minerals are: Kaolin, muscovite, in veinlets, a white mica without potash, chlorite, and calcite.[a]

There is so much irregularity in the dimensions of the particles of this granite that the Rosiwal method of determining the mineral percentages was not practicable.

[a] A microscopic description of Concord granite by G. W. Hawes will be found in his Mineralogy and lithology of New Hampshire, which forms vol. 3, pt. 4, of C. H. Hitchcock's Geology of New Hampshire, 1878.

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But one chemical analysis of Concord granite is available. That is given on page 150. The specific gravity of the stone was determined by Crosby as 2.64 and 2.65, averaging 2.65, or 155.6 pounds per cubic foot.

Messrs. Steiger and Schaller, chemists, of the United States Geological Survey, find as the result of two tests that Concord granite contains from 0.15 to 0.17 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates a content of from 0.26 to 0.30 per cent of $CaCO_3$ (lime carbonate), and the microscope also shows the presence of carbonate.

Two tests of compressive strength, made at the United States arsenal at Watertown, Mass., show a compressive strength of 30,830 pounds per square inch with pressure applied at right angles to rift, and of 23,860 pounds when applied parallel to it. There is thus a loss of 12½ per cent of compressive strength in the rift direction. A more recent test made at the same place gave this stone a compressive strength of 23,670 pounds, direction of rift and grain not stated.

The polish of Concord granite is fair, but the abundant mica plates and the size of some of them do not favor the durability of the polish under long-continued outdoor exposure. The muscovite appears much darker when polished. No pyrite was detected in the polished specimens or thin sections, although the chemical analysis indicates its probable presence. There is considerable contrast between the rough and hammered faces. Its general bluish cast is marked particularly on the polished face, but the rough face becomes lighter on continued exposure. There is some variation in the amount of mica apparent on the different faces of a block, as well as a difference in the actual amount of black mica and in the sparseness of the large feldspars in the stone from different quarries. Only on close inspection do strong contrasts appear between the bright muscovite plates, the fine black biotite scales, and the glassy feldspar.

The Concord quarries.— The New England Granite Works quarry is in the upper part of Rattlesnake Hill, roughly northwest of Concord. Operator, The New England Granite Works, 20 Ferry street, Concord, N. H.

The granite (specimens D, XXVIII, 39, a, b, f, g), "Concord granite," is a muscovite-biotite granite of medium bluish-gray color, and fine to medium, somewhat porphyritic texture, with sparsely disseminated larger feldspars up to 0.4 inch (exceptionally 0.5 inch), and micas, from very minute size up to 0.2 inch (exceptionally 0.4 inch). It consists, in descending order of abundance, of a slightly bluish translucent potash feldspar (microcline, mostly in long twins, less orthoclase), inclosing quartz and soda-lime feldspar particles; clear to faintly amethystine quartz with abundant hairlike crystals, probably of rutile, also with sheets of cavities; milk-white more or

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less kaolinized and micacized soda-lime feldspar (oligoclase-albite) containing rare particles of carbonate, probably calcite; white potash mica (muscovite); and black mica (biotite), mostly in smaller scales than the muscovite or with their flat sides at right angles to the muscovite scales. The accessory minerals are: Magnetite (some within biotite), apatite, zircon, and rutile. The secondary are: Kaolin, muscovite in veinlets, white mica without potash, and calcite.

Mr. George Steiger, chemist, of the United States Geological Survey, finds that this granite contains 0.15 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates a content of 0.26 per cent of $CaCO_3$ (lime carbonate), the presence of which carbonate is also indicated by the microscope.

A test of the compressive strength of this granite, made at the United States arsenal at Watertown in 1907, gave the following results: A cube of approximately 2-inch edge showed the first crack at 86,000 pounds and was crushed at 94,200 pounds, thus having an ultimate compressive strength of 23,670 pounds per square inch. It does not appear whether the pressure was applied in the rift or grain direction.

The granite of this quarry appears to be more biotitic and to have its larger feldspars more sparse than the stone of the other Concord quarries.

The quarry, opened in 1812, is about 350 feet from northeast to southwest by 300 feet across and has a working face on the southwest 130 feet in height.

The sheets range from 6 inches thick in the upper 30 feet of the working face to 40 feet at the bottom, and dip from 10° to 15° SE. Some of the sheets, owing to their freedom from rusty discoloration, are regarded by the foremen as of recent origin and are called "strain sheets;" and even now a northwest-southeast compressive strain occasionally extends these sheets.[a]

There are two sets of joints: Set A, striking N. 62° E. and vertical, forms headings on the northwest and southeast sides and recurs in the middle, but is apt to be discontinuous. Set B, striking N. 45° W. and dipping 35° NE., is represented by only two on the northwest wall which are 5 feet apart. The rift is reported as horizontal and the grain as vertical and exactly east-west. Two 6-inch pegmatite dikes, 20 feet apart, and several an inch thick, traverse the quarry vertically with a N. 30° E. course. The thick ones are banded, consisting of a central 1½- to 2-inch band of aplitic material with a half-inch border on one or both sides made up of coarse pegmatite, milk-white oligoclase and microcline, and smoky quartz. Very fine garnets occur throughout these dikes, some in bands, and here and

[a] See p. 28.

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there a small beryl. There are also half-inch muscovitic veins, "sand streaks" (p. 51), striking N. 45° W., and consisting of a central band of muscovite and quartz, with borders of quartz and feldspar. Gray and black knots of the micas measure up to 6 by 5 inches. Light rusty stain measures from 6 inches to 2 feet on the sheet surfaces, but for 100 feet vertically in the center of the quarry the sheets have little or none of it.

The plant, including the cutting machinery at the company's sheds in Concord, comprises 6 derricks, 6 hoisting engines, 4 overhead electric traveling cranes (capacity 15 and 20 tons), 4 air compressors (capacity three of 750, one of 500, cubic feet of air per minute), belt driven from a dynamo, 4 large rock drills, 15 air plug drills, 24 air hand tools, 8 surfacers, a stone saw (Lincoln patent with Hawley sand feed) for blocks 15 feet long, 4 stone lathes (2 for stones 20 and 23 feet long, and 2 for balusters), and 3 steam pumps.

Transportation is effected by cartage of about five-eighths mile to a siding of the Boston and Maine Railroad, but the laying of a gravity track was in contemplation in 1906.

The product consists mainly of building stone. Thin sheets and waste furnish about 100,000 paving blocks per annum as a by-product. Specimen structures: The four outer walls and the covered driveway of the Congressional Library, the outside and inner court walls of the basement of the United States Senate Office Building; Blackstone Library, Chicago; German Savings Bank and Christian Science Church in New York; Camden County court-house, at Camden, N. J.; German-American Savings Bank, at Pittsburg, Pa.; Manufacturers and Traders' Bank, at Buffalo, N. Y.; Assabet River bridge, Northboro, Mass., and Early Settlers monument, at Galveston, Tex.

The Granite Railway quarry (of Concord) or Upper Swenson quarry[a] is on Rattlesnake Hill, about N. 40° W. from the statehouse at Concord and 260 feet above it. Operator, John Swenson, Concord, N. H.

The granite (specimens D, XXVIII, 40, c, e), "Concord granite," is a muscovite-biotite granite of medium bluish gray color and fine to medium somewhat porphyritic texture, with feldspars up to 0.5 and mica plates to 0.2 inch. Feldspar appears to be relatively more abundant and biotite less so than in the stone of the New England Granite Works quarry (p. 147). In other respects the two granites are identical. A section cut at right angles to the rift shows that the mica plates, both black and white, lie with their flat sides parallel to the rift.

The following analysis of this granite was made by Sherman and Edwards, chemists, from a "thoroughly composite sample carefully

[a] This quarry owes its first name to the fact that it was originally operated by the Granite Railway Company of Quincy, Mass., referred to on p. 109.

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selected" by Prof. W. O. Crosby, of the Massachusetts Institute of Technology. This analysis forms part of a report made by him for the firm in 1907, and is published here merely for reference.

Analysis of Concord granite from Swenson quarries.

SiO_2 (silica)	74.47
Al_2O_3 (alumina)	14.15
Fe_2O_3 (iron sesquioxide)	1.16
FeO (iron oxide)	1.21
MgO (magnesia)	.63
CaO (lime)	1.70
Na_2O (soda)	1.97
K_2O (potash)	4.14
S (sulphur)	.27
CO_2 (carbonic dioxide)	.25
H_2O (water not combined)	.06
H_2O (water combined)	.20
	100.21

Professor Crosby, in the same report, gives two determinations of specific gravity: 2.64 and 2.66, average 2.65, which is equivalent to 155.6 pounds per cubic foot.

Mr. W. T. Schaller, chemist, of the United States Geological Survey, finds that this granite contains 0.17 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates the presence of 0.30 per cent of $CaCO_3$ (lime carbonate).

Compression tests made at the United States arsenal at Watertown, Mass., in 1906 show it to have an ultimate compressive strength of 30,830 pounds per square inch with pressure applied at right angles to rift, but of 23,860 pounds with pressure applied in the direction of the rift, the rift thus weakening the stone 12½ per cent when pressure is applied parallel to it.

The quarry, opened in 1863, measures about 500 feet north-northeast to south-southwest by 400 and 200 feet in width, and from 10 to 100 feet in depth.

The sheets are irregular, lenticular, and from 4 inches to 14 feet thick, but mostly from 2 to 7 feet, and dip northwest at a low angle. There are two sets of joints: Set A, striking N. 20° E. and dipping 70°–75° E., is spaced 10 to 100 feet and forms the west wall and a heading 50 feet wide on the east side. Set B, striking N. 65° W. and vertical or dipping 75° S, is spaced 10 to 300 feet, and forms the north wall and a heading 6 to 15 feet wide on that side. The rift is reported as dipping 15° W., with a strike of N. 5°–10° E., and the grain as vertical east-west. In summer time it is not necessary to follow the grain closely in splitting. There are pegmatite dikes up to 1½ inches wide. Segregations of the micas are said to be very rare and to measure only 4 inches. Rusty stain is up to 8 inches wide, but is confined to the proximity of headings. A little com-

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pressive strain in an east-west direction is reported. The joint faces of headings B are dull greenish in color, owing to chloritization of biotite and the formation of fibrous muscovite in the feldspar and between the particles. The soda-lime feldspars also contain chlorite and carbonate. Other joint faces of the same set carry secondary quartz and calcite crystals and apparently also fluorite, deep purple and white. (See p. 61.)

The plant, including that of the lower quarry of same firm, described on this page, and that of the firm's cutting shed on North State street, comprises: 7 derricks, 4 hoisting engines, an electric overhead crane (capacity 15 tons), a Rand air compressor (capacity 750 cubic feet of air per minute), 4 large drills, 12 air-plug drills, 55 air hand tools, 3 surfacers, 3 "Jenny Lind" polishers, a vertical polisher, 5 pendulum polishers, and 2 steam pumps.

Transportation involves cartage of one-third mile to cutting sheds, which are on a siding of the Boston and Maine Railroad.

The product is used for buildings and monuments, and finds a market mostly in the West. Specimen structures: City hall and Christian Science Church, Boston; Northampton County Savings Bank, Easton, Pa.; Post-offices at Lincoln, Nebr., Adrian, Mich., and Hammond, Ind.; pedestal of the Monaghan monument, Spokane, Wash.; New Hampshire soldiers' monument, Vicksburg, Miss.; pedestal and exedra of McKinley Memorial, McKinley Park, Chicago. In 1906 the firm was filling contracts for the Citizens' National Bank, St. Clair, Pa.; Medico-Chirurgical Hospital, Eighteenth and Cherry streets, Philadelphia; and the electric station of the New York Edison Company, East Thirty-ninth street, New York.

The Hollis quarry (*Lower Swenson*) is about 600 feet northeast of the last and 70 feet below it. It is also operated by John Swenson, Concord, N. H.

The granite is identical with that of the upper quarry just described.

The quarry, opened about 1864, measures about 450 feet north-south by 300 feet across and from 40 to 50 feet in depth.

The sheets are irregular lenticular and horizontal or dip 15° W. They are from 6 inches to 35 feet thick. There are two sets of joints. Set A, striking N. 25° E. and dipping 65°–70° E., is spaced 10 to 50 feet, and forms headings on the west and east sides and another 50 feet east of west wall. Set B, striking N. 65° W. to east-west and about vertical, is spaced 20 to 75 feet and forms the northeast wall. There are several inclusions of banded gneiss, one 3 feet 6 inches by 2 feet, another, originally much larger, now measures 4 feet 6 inches in diameter and is roughly quadrangular. Part of this is pegmatitic and part a biotite gneiss, with soda-lime feldspar (oligoclase-andesine) and garnets. In the finer parts the particles do not exceed 0.37 millimeter in diameter. The rift and grain are

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reported as the same as at the upper quarry. One-inch pegmatite dikes cross the quarry diagonally. Rusty stain on the upper sheets is up to 8 inches thick. The granite along heading A on the west wall is much kaolinized and in places very limonitic. The surfaces have frostlike crystallizations (dendrites), probably of limonite also.

The plant and product of this quarry have been combined with those of the Granite Railway quarry on page 151.

The Anderson quarry is about 2 miles, roughly, N. 25° W. of the statehouse and 300 feet west of North State street, opposite Park street. This is the most northerly of the Concord quarries. Operator, Ola Anderson, Concord, N. H.

The granite, "Concord granite," is a muscovite-biotite granite of medium bluish-gray color and fine to medium, somewhat porphyritic texture, like that of the Granite Railway or Lower Swenson quarry, described on page 149.

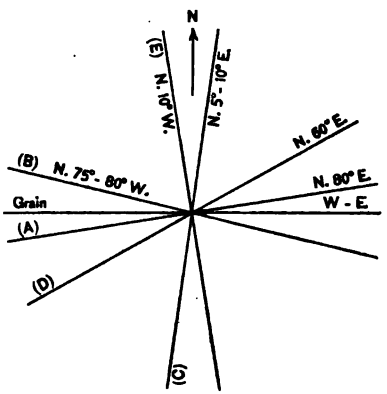

FIG. 19.—Structure at Anderson quarry, Concord, N. H.

The quarry, opened between 1860 and 1870, measures about 200 feet northwest-southeast by 175 feet across and 35 feet in depth. A second adjacent opening is 50 feet square and 10 to 15 feet deep.

The sheets, from 6 inches to 6 feet thick, are irregular lenticular and dip low west. There are five sets of joints, whose courses are shown in fig. 19.

Set A, vertical, is spaced 3 to 10 feet and forms the west wall. Set B, vertical, is spaced 10 to 30 feet and forms the northwest wall. Set C dips 55°–75° E., is spaced 200 feet, and occurs at north and southwest corners. Set D dips 50° SE. and forms heading on the southeast side. Set E dips 70° E. and forms a heading on the same side, intersecting Set D. The rift is reported as about horizontal and the grain as vertical with east-west course. Knots are reported up to 2 inches in diameter and rusty stain from one-fourth to 10 inches thick.

The plant consists of 5 derricks, 2 hoisting engines, an air compressor (capacity 237 cubic feet of air per minute), a large drill, 4 air plug drills, 8 air hand tools, and 3 surfacers.

Transportation is effected by a siding from the Boston and Maine Railroad.

The product is used chiefly for buildings and the waste for paving blocks. Specimens: Soldiers and sailors' memorial arch in front of statehouse, Concord; post-offices at Kankakee, Ill., and Gloversville,

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N. Y.; base course and first story of post-office at Jamestown, N. Y.; sarcophagus monument to Mrs. Gilbert, Goodland, Ind.; Gerhardt mausoleum at Bushwick Junction, Long Island.

The Crowley quarry is about 300 feet south of the Anderson quarry, near North State street. Operator, P. Crowley, 434 North State street, Concord, N. H.

The granite, "Concord granite," is a muscovite-biotite, medium-gray granite, presenting no special variations from the general type described on page 146.

The quarry, opened in 1865, is about 240 feet northeast-southwest by 100 feet across, and from 35 to 50 feet deep.

The sheets, from 6 inches to 25 feet thick, are horizontal or dip gently southwest. There are four sets of joints. Set A strikes N. 30° E., dips 65°–70° E., and is spaced 3 to 25 feet. Set B strikes N. 60°–65° W., is vertical, and is spaced 50 feet. Set C strikes north, is vertical and diagonal, and occurs on the northwest wall. Set D strikes N. 10° E., dips 50° E., and is spaced 100 feet. In the center of the quarry is an inclusion of dark banded biotite-muscovite-oligoclase gneiss of slight purplish hue. It was originally 30 feet high and pointed at the top. It measures 30 feet in diameter at the base, which is nearly round on one side, but rectangular on the other. A 2-inch pegmatite dike crosses the schistosity of the gneiss, but ends abruptly at the granite contact. Another part of this inclusion consists of porphyritic granite with feldspars an inch long. The rift is reported as horizontal or dipping N. 65° W. In splitting sheets from the west the rift is said to be inclined, but in splitting from the east horizontal. The grain is said to be vertical with east-west course when frozen, but in summer to be very feeble. A 1 to 2 inch pegmatite dike with a N. 45° E. course branches irregularly. There are geodes of coarse feldspar, smoky quartz, and muscovite of half-bushel size. Rusty stain measures from 6 to 18 inches thick, but less on the lower sheets.

The plant consists of 2 derricks, a hoisting engine, and a steam drill.

Transportation is by a siding from the Boston and Maine Railroad, but by cartage to local cutters.

The product is used for buildings, monuments, curbing, and paving. Specimen: The trimmings on the new high school at Concord.

The Henneberry & Halligan quarry is on Rattlesnake Hill, one-fourth mile west of North State street and 70 feet above it, at a point one-fourth mile north of the State prison. Operators, Henneberry & Halligan, Concord, N. H.

The granite (specimens D, XXVIII, 49, a, c), "Concord granite," is a muscovite-biotite granite of medium bluish gray color, and fine to medium, somewhat porphyritic texture, with feldspars up to 0.5

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and white mica scales up to 0.2 inch. This stone resembles more closely that of the New England Granite Works quarry than that of the Swenson quarries, being more micaceous and less feldspathic than the latter, but the black mica scales are generally finer than in the former, so that it has a larger number of fine particles. The firm regards the stone as harder than that of the other Concord granites. The constituents are the same as in the sections already described on pages 147, 148. The soda-lime feldspar is oligoclase and contains some secondary calcite.

The quarry, opened in 1900, is about 200 feet N. 25° E., by 100 feet across, and from 50 to 65 feet deep.

The sheets, from 2 to 15 feet thick, are somewhat irregular and horizontal or dip 17°–30° NE. There are 2 sets of joints. Set A, discontinuous, strikes N. 25° E., is spaced 3 to 15 feet, and forms a heading at the northeast end. Set B, strikes about northeast, diagonal, and is spaced 12 to 25 feet. The rift is reported as horizontal or nearly so, and the grain as vertical with a northeast course. Three garnetiferous pegmatite dikes, 1 to 4 inches thick, in a space of 2½ feet, strike about N. 45° W. and dips 60° SE. Rusty stain is about 4 inches thick on sheet surfaces.

The plant, at the quarry, includes 3 derricks, a hoisting engine, a steam drill, and a steam pump. At the cutting shed in Concord it comprises 2 derricks, 2 air compressors (capacity 135 and 78 cubic feet of air per minute), 2 electric motors, an air plug drill, a surfacer, and an air hand tool.

Transportation involves cartage of one-eighth mile to Boston and Maine Railroad, or 1¼ miles to cutting shed on Prospect street.

The product is used entirely for monuments. Specimens: Fay sarcophagus, Dewitt, Iowa; Sielaff sarcophagus, Milwaukee, Wis.; Raines sarcophagus, Memphis, Tenn.; McElwee sarcophagus, Homer, Ill.; Alten cross, Elyria, Ohio. In 1906 an elaborately carved sarcophagus (Crippen) was being cut for the Blossom Hill Cemetery, Concord, and several for Syracuse, N. Y.

The Fox quarry is on Rattlesnake Hill, 110 feet above North State street, N. 43° W. from the statehouse, and about half a mile N. 40° E. from the New England Granite Works quarry. Operator, Thomas Fox, 272 North State street, Concord, N. H.

The granite, "Concord granite," is a muscovite-biotite granite of medium bluish gray color and fine to medium somewhat porphyritic texture, resembling that of the Granite Railway quarry more than that of the New England Granite Works quarry. (See p. 149.)

The quarry, opened in 1884–5, a plan of which is given in fig. 20, measures about 200 and 300 feet by 175 feet across and from 40 to 70 feet deep.

The sheets are, for this region, exceptionally regular, dip 10° SW., and from 2 to 20 feet thick. There are 3 sets of joints. (See fig. 20.)

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Set A, vertical to steep east-southeast, is spaced 3 to 30 feet and forms east and west walls and the headings on the east side and center. Set B, vertical to steep east, is spaced 10 feet and over. Set C, spaced 10 to 70 feet, is apt to be discontinuous. The rift is reported as dipping 5°–7° SW. and the grain as vertical with a N. 70° E. course. The stone splits more easily along the rift in winter than in summer. In the northern part a 10-foot band of granite, without the bluish tint of the rest, strikes N. 60° W. and dips 90°. The cause of the difference is not clear, unless it be the micacization of the potash feldspar. It contains zonally arranged particles of quartz and oligoclase. The course of this band presumably indicates the flow direction of the granite. On one or both sides of it is an inch vein of muscovite. Pegmatite dikes measure up to 1½ inches in thickness. There are spheroidal segregations, from 6 inches to 3 feet by 2 feet 6 inches, of a porphyritic granite of bluish gray shade, darker than any Concord granite. The matrix is fine-textured (particles 0.18 to 0.74 millimeter); the feldspars measure up to 0.4 inches, and the mica to 0.2 inches. The constituents are the same as those of Concord granite. The sheet surfaces are mostly free from rusty stain, and it is said never to exceed 4 inches in thickness. One of the joint faces carries chlorite, calcite, and pyrite.

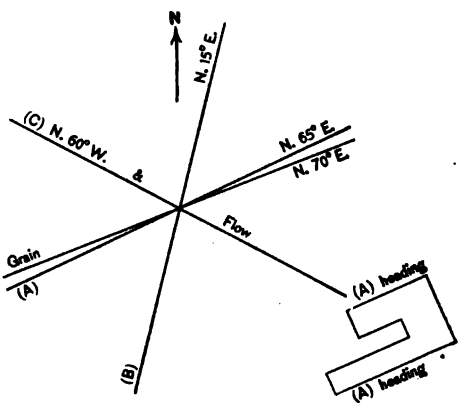

FIG. 20.—Structure and plan of Fox quarry, Concord, N. H.

The plant, including that of the cutting shed on North State street, comprises 3 derricks (one with a 95-foot mast and a 75-foot boom), 2 hoisting engines, an air compressor (capacity 140 cubic feet of air per minute), 2 steam drills, an air plug drill, 15 air hand tools, a surfacer, 3 "Jenny Lind" polishers, and a steam pump.

Transportation involves cartage of one-fourth mile to a siding of the Boston and Maine Railroad, or of three-fourths mile to the cutting shed.

The product is used for buildings and monuments. Specimens: Church of Christ, Scientist, Concord, N. H.; Shelden Library, St. Paul's School, Concord; entrance to Forest Lawn Cemetery, Buffalo; Soldiers' monument, Warner, and Carpenter tomb, Manchester, N. H.

The Perry quarry is on Rattlesnake Hill, N. 50° W. from the statehouse and 360 feet above North State street. This is the most southerly of the Concord quarries. Operator, W. H. Perry & Co., Concord, N. H.

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The granite, "Concord granite," is a medium bluish gray muscovite-biotite granite of fine to medium somewhat porphyritic texture, closely resembling that of the New England Granite Works quarry described on page 147.

The quarry, opened in 1873, measures 250 feet N. 75° W. by 125 to 250 feet N. 10° E., and from 60 to 100 feet in depth.

The sheets, from 1 to 18 feet thick, are about horizontal. There are 4 sets of joints. Set A, striking N. 10° E. and dipping steeply east, is spaced 5 to 20 feet. Set B, striking N. 75° W. and vertical, is spaced 18 to 35 feet. Set C, striking N. 30° E. and dipping 50° E., is spaced 200 feet. Joint D, striking N. 45° W. and dipping 75° S. 45° W., occurs only at the northeast corner. That corner is much jointed and some of the joints are exceptional. The rift is reported as horizontal, and the grain as vertical with N. 80° W. course. A 4 to 5 inch pegmatite dike occurs with a N. 85° W. course and a vertical dip. Rusty stain does not exceed 4 inches and is absent from some sheets.

The plant, including that of the cutting shed in Concord, comprises 4 derricks, a hoisting engine, an air compressor, 7 air hand tools, 2 surfacers, a steam drill, 3 "Jenny Lind" polishers, a polishing lathe for stones 8 by 4 feet, an electric motor, and 2 steam pumps.

Transportation involves 3 miles' cartage from the quarry to the cutting shed, which is on the Boston and Maine Railroad.

The product is used mostly for monuments. Specimen: George Fogg monument, in Blossom Hill Cemetery, Concord, N. H.

The Duffy prospect is on Rattlesnake Hill, N. 50° W. from the statehouse and 40 feet lower than the Perry quarry. Operator, N. J. Duffy, Concord, N. H.

The granite, "Concord granite," corresponds to that of the New England Granite Works quarry described on page 147.

The quarry, opened in 1906, measures about 50 feet east-west by 25 feet across and but a few feet in depth.

The sheets are thick. Joints will probably be found to be similar to those at the Perry quarry. Knots, 2 inches in diameter, and a 2-inch pegmatite dike were noted.

The plant consists of 2 derricks and 1 engine.

Transportation is by cartage of a mile to the cutting shed, which is on the Boston and Maine Railroad.

MILFORD, N. H.

Topography.—The Milford quarries lie within a radius of 4 miles of Milford village and between southwest, south, and southeast directions from it. A few lie northwest of it. The region about Milford, as shown on the Milford, N. H., topographic sheet of the United States Geological Survey, is marked by hills and short ridges, from 440 to 760 feet above sea level, trending north to south or north-

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northeast to south-southwest. The highest of these hills are, Burns Hill (720 feet) and Badger Hill (760 feet), southwest of the village, and Federal Hill (700 feet) southeast of it. This hilly surface is, however, bisected east and west by the valley of Souhegan River,

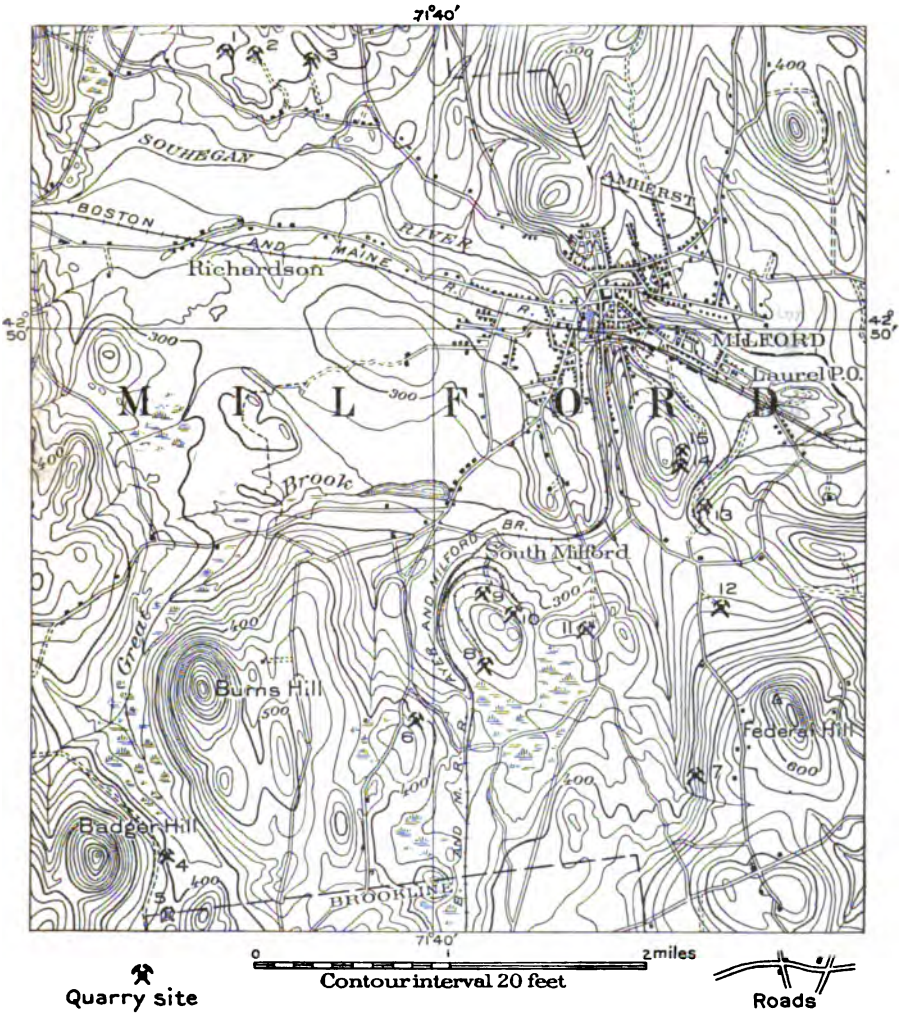

FIG. 21.—Map of vicinity of Milford, N. H., showing locations of granite quarries. 1, New Westerly quarry, New Westerly Granite Company. 2, Carlton quarry, A. E. Carlton. 3, Bishop quarry, John B. Bishop. 4, Comolli quarry, Comolli Bros. & Co. 5, Paradise quarry, Milford, Nashua Lake Street Granite Company. 6, Tonella New quarry, Tonella & Sons. 7, Souhegan quarry, Daniels Granite Company. 8, Lovejoy quarry, Lovejoy Granite Company. 9, Pease quarry, Milford Quarry and Construction Company. 10, Kittredge quarry, Edward L. Kittredge. 11, Tonella Old quarry, Tonella & Sons. 12, Hayden quarry, Henry W. Hayden. 13, Young quarry, Young's Sons & Co. 14, Milford Granite Company, south opening. 15, Milford Granite Company, north opening.

which hereabouts flows between the 206 and 240 foot levels. The locations of the quarries, shown on the map (fig. 21), are not governed by the topography. None of them are above the 400-foot level or 130 feet above the bench mark at Milford village.

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Geology of Milford, N. H., quarries.—The most interesting geological features of the Milford granite quarries are the contact phenomena and inclusions. The former have been fully described on page 62 and are illustrated in fig. 5 and Pl. VI, *A*. At these places remnants of the gneisses which once probably overlay the granite mass of the entire region are preserved. As these gneisses are evidently themselves granitic rocks which under powerful compression have undergone chemical and textural changes and become schistose, we are led to conclude that the Milford region has been the scene of two intrusions of rock material in molten condition, with an intervening period of metamorphism. The gneiss now capping the granite at the quarries of the Milford Granite Company (p. 173) represents the earlier granitic rock metamorphosed, the presence of which supplied part of the pressure which made possible as granite the stone which is now quarried.[a] The strike of the gneiss foliation is N. 75° W., which furnishes a clue to the direction from which came the compression which metamorphosed the earlier granite. It is assumed, of course, that these few feet of gneiss are but the shreds of a mass which originally measured many hundred feet in thickness, but which was eroded mainly in preglacial time. The pegmatite dikes, which, apparently starting at the contact, run up into the gneiss, as shown in Pl. VI, *A*, were probably formed at the time of the intrusion of the underlying granite. This original gneiss of the region is also exposed at the Tonella quarries. (See pp. 164, 165.) At two quarries fragments of coarse biotite gneiss occur as inclusions in the granite. (See pp. 169, 176.) These probably formed part of the same overlying gneiss, which indeed they closely resemble. This was fractured by the vertical and lateral strain accompanying the intrusion, and fragments fell into the rising semiliquid fused mass. There is also at several quarries a marked banding in the granite, with courses of N., N. 15°, 20°, 50°, 70° E., and N. 75°–80° W., which must have been caused by the granite current (flow structure). At the Daniels quarry (p. 169) a roughly diamond-shaped inclusion of gneiss, over 3 feet in diameter, has a flow structure about it parallel to its surface, showing that while the plastic material was adjusting itself to the foreign body a zonal rearrangement of the mineral constituents of the granite took place. The occurrence of pegmatite dikes in groups of parallel courses in Milford granite has already been discussed (p. 48), and is shown in Pl. VI, *B*. The courses of pegmatite dikes at the quarries are N. 20°, 25°, 30°, 75° E. and N. 20°, 25°, 50°, 65° W. These must be attributed to a secondary intrusion in the granite in openings possibly due to contraction. The pegmatites thus represent a third access of heated matter to this portion of the crust. Finally the basic dikes, noted on pages 162, 163, 167,

[a] See Bull. U. S. Geol. Survey No. 313, pp. 14–16.

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A. CONTACT OF GRANITE AND OVERLYING GNEISS AT MILFORD GRANITE COMPANY'S QUARRY, MILFORD, N H., LOOKING WEST-NORTHWEST.

Pegmatite dikes in gneiss. Sheet structure in both rocks, but disconnected.

B. PEGMATITE DIKES IN GROUPS AT THE YOUNG GRANITE QUARRY, MILFORD, N. H, LOOKING NORTH-NORTHWEST.

A typical heading at the left: freshly cleared hummocky surface at top.

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represent a fourth and probably much later injection of rock material in molten condition. The effect, direct or indirect, of these dikes in reddening the adjacent granite is very noticeable (see pp. 163, 167), and appears to be due to the hematitization of the feldspars either by the oxidation of magnetite by water or by the deoxidation of limonite by heat. The most abundant set of joints strikes N. 70°–85° W., its complementary set striking N. 10°–30° E. Others strike N., N. 35°–40°, 45°–50°, 60° E. and N. 30°, 50°, 60° W. The rift is reported at all the quarries as either horizontal or inclined at a very low angle south or S. 70° W. or west. The grain is reported as vertical or dipping 70° north with a course of N. 60°–90° W., in one place N.80°E. The sheets are from 3 inches to 30 feet thick.

Description of Milford, N. H., granite.—The following combines all the more detailed descriptions of specimens and thin sections given on pages 160–176.

Milford, N. H., granites are quartz monzonites [a] of light, medium, and dark-gray shade, in places of a slight bluish, pinkish, or buff tinge, and always spangled with black mica. Their texture is, with one exception, even grained, and very fine to fine, with feldspars and mica in the very fine up to 0.1 inch and in the fine to 0.2 inch. The constituents of these monzonites, in descending order of abundance, are: Clear to slightly smoky quartz with cavities (in sheets) up to 0.008, 0.017, 0.03 millimeter, and in some quarries with hairlike crystals, probably of rutile; clear, colorless to milk white, or bluish, greenish, or pinkish soda-lime feldspar (oligoclase), somewhat kaolinized and micacized; clear, colorless to milk white, or bluish, greenish, pinkish, or cream-colored potash feldspar (microcline with or without orthoclase), in places slightly kaolinized and micacized; black mica (biotite), some of it chloritized or bleached. Both feldspars are intergrown with quartz circular in cross section. The accessory minerals are: Magnetite, pyrite, apatite, zircon, allanite, and rutile; the secondary: Chlorite, two white micas, carbonate, kaolin, limonite, and hematite.

Estimates of the mineral percentages by the application of the Rosiwal method to camera lucida drawings of 3 thin sections of the very fine Milford granite from 3 widely separated quarries (pp. 164, 170, 173) yield the following results:

Average estimates of mineral percentages in Milford, N. H., monumental granite.

Quartz	27.09
Soda-lime feldspar (oligoclase)	34.03
Potash feldspars (microcline 14.15; orthoclase 15.57)	29.72
Black mica	8.58
Magnetite	.25
Minor accessories	.33
	100.00

[a] See Glossary, p. 219.

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As the percentages of quartz, soda-lime feldspar, and mica varied considerably in the separate estimates, the averages for these minerals are more dependable.

The average diameter of the particles in these three granites, as determined by the same method, is 0.0095 inch, which is about the same as the average of three Westerly, R. I., "blue granites," given on page 192 as 0.0099 inch.

Messrs. Sullivan, Schaller, and Steiger, chemists, of the United States Geological Survey, found that granite from 5 Milford, N. H., quarries contained from 0.11 to 0.26 per cent of CaO (lime) soluble in hot dilute acetic acid, or an average of 0.16 per cent, which indicates a content of from 0.19 to 0.46 per cent, or an average of 0.29 per cent, of $CaCO_3$ (lime carbonate). The presence of this carbonate is also shown by the microscope and by effervescence with cold dilute muriatic acid.

The finer Milford granites, which are properly monumental granites, take a high polish, to which the fineness of the mica contributes. The hammered face of these quart zmonzonites offers quite a little contrast to the polished face, owing to their large percentage of soda-lime feldspar. The particles are so fine that the only contrast, that between the mica and the other particles, is only visible at a short distance. In the coarser Milford granites, in which the mica measures 0.2 inch in two of its diameters, this contrast is more marked. The chief characteristics of all these finer granites are the uniformity and delicacy of their shade or tint, the variety of tints obtainable at the different quarries, and the adaptability of the stone for fine carving. The coarser Milford granites are entirely constructional.

The Milford, N. H., quarries.—The Lovejoy quarry is in South Milford, about 2 miles S. 25° W. of Milford village, on the 380-foot level, on the southwest side of an oblong hill 440 feet high. (See fig. 21.) Operator, Lovejoy Granite Company, Milford, N. H.

The granite (specimen D, XXVIII, 51, b) is a quartz monzonite of light-gray shade spangled with black mica. Its texture is even grained, fine, inclining to medium, with feldspars and mica up to 0.2 inch. It consists, in descending order of abundance, of a milk-white potash feldspar (microcline and orthoclase); in almost equal amount a clear to milk-white soda-lime feldspar (oligoclase), partly kaolinized and micacized; light smoky quartz; biotite (black mica), some of it chloritized. Accessory minerals are: Allanite, zircon, apatite. Secondary: Chlorite, two white micas, kaolin, carbonate, and hematite.

Mr. George Steiger, chemist, of the United States Geological Survey, finds that this granite contains 0.14 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates the content of 0.25 per cent

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of $CaCO_3$ (lime carbonate); the microscope also shows the presence of a carbonate, and the stone effervesces slightly with dilute muriatic acid.

The quarry, opened about 1886, measures 477 feet N. 35° E. by 150 feet across and from 5 to 20 feet in depth.

The sheets, from 3 inches to 10 feet thick, but mostly up to 5 feet 6 inches, dip 5° to 10° east and southeast. There is but one set of joints, which is vertical, striking N. 85° W., recurs at intervals of 40, 100, and 330 feet, and forms a 4 to 10 foot heading 140 feet from the north end. The rift is reported as horizontal but tending to incline with the sheets, the grain as vertical with N. 85° W. course. In summer the rock splits without reference to rift and grain. A flow structure, shown by more micaceous bands alternating with some 2-inch white ones, strikes N. 40° W. and dips 25° NE. Pegmatite dikes, up to 2 inches thick, strike N. 65° W., exceptionally N. 25° E. They consist of half-inch particles of clear to milky striated soda-lime feldspar (oligoclase), light smoky quartz, and black mica with magnetite and pyrite. There are no knots. Rusty stain is light, and up to 6 and 18 inches thick, but is not present on all sheets.

The plant consists of 3 derricks, 2 hoisting engines, an air compressor (capacity 935 cubic feet of air per minute), 2 large drills, 12 air plug drills, 2 surfacers, and a steam pump.

Transportation, as shown on the map (fig. 21), is by siding from the Boston and Maine Railroad.

Specimen structures: Pier 4 of Haverhill bridge, Essex County, Mass.; piers 4 and 6 of the railroad bridge at the same place; trimmings of Majestic Theater, Chicago; and Ferguson mausoleum at Kenrico Cemetery, New York.

The Kittredge quarry is in South Milford, about 1½ miles S. 15° W. of Milford village, on the 360-foot level, on the opposite side of the same hill the Lovejoy quarry is on. (See fig. 21.) Operator, Edward L. Kittredge, Milford, N. H.

The granite (specimen D, XXVIII, 50, b) is a quartz monzonite of light-gray shade (with very slight bluish tinge apparent when the stone is in large masses) spangled with black mica. Its texture is even grained, fine, inclining to medium, with feldspars up to 0.2 and mica to 0.1 inch. In 4 thin sections the particles do not exceed 2.96 milimeters, or 0.012 inch, and most of them are not 2.2 milimeters or 0.08 inch. At very rare intervals porphyritic feldspars occur up to 1½ inches in diameter. Its constituents, in descending order of abundance, are: Very slightly bluish milk-white potash feldspar (microcline intergrown with quartz, and orthoclase); in almost if not quite equal amount clear, colorless to milk-white soda-lime feldspar (oligoclase), partly micacized and kaolinized; light smoky quartz with sheets of cavities and rift or grain cracks parallel to them; and biotite (black mica), some of it chloritized. Accessory minerals are:

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Magnetite, allanite, zircon, and apatite. Secondary: Kaolin, chlorite, white mica, and limonite. In the upper sheets the stone is of light cream color owing to limonite proceeding from magnetite and allanite particles.

A very fine monumental granite (specimen D, XXVIII, 50, a), forming a band 20 feet wide at the south end of the quarry, is also a quartz monzonite of light-gray shade with very slight bluish tinge and spangled with fine black mica. Its texture is very fine, with feldspars rarely over 0.1 and mica not over that. In thin section the feldspars measure up to 1.85 millimeters and the mica 0.74 millimeter. The constituents are like those of the coarser stone but the potash feldspars appear to predominate. The quartz contains hair-like crystals, probably rutile, and sheets of cavities intersecting at right angles, with cracks parallel to at least one of the sets of sheets.

The main product (specimen 50, b) is a constructional granite closely resembling that of the Lovejoy quarry on the other side of the hill but with slightly finer mica scales and a more bluish tinge in large masses. It effervesces very slightly with dilute muriatic acid.

The quarry, opened about 1890, measures 800 feet north-south by 200 feet across and from 5 to 40 feet in depth. The working face is on the southwest.

The sheets are lenticular, from 4 inches to 2 feet 10 inches thick, and dip at a low angle north and east. There are 3 sets of joints: Set A striking N. 22° E. and vertical, forms a heading 5 to 7 feet wide on each side of a basic dike. Set B, striking N. 70° and vertical, is spaced 200 feet. Set C, striking N. 45° E. and dipping 55° N. 45° W., is exceptional. The rift is reported as horizontal and the grain as vertical with a N. 80° E. course. A flow structure marked by parallel bands of abundant black mica strikes N. 20° E. also N. 50° E., with a dip of 20° NNW. and NW. A basic dike, a foot thick, striking N. 22° E. and vertical forms the east wall. This is intimately related to joint system A. Pegmatite dikes, 1½ to 3 inches thick, strike N. 20° and 50° W., forming in one place a network with meshes 15 feet square. An obscure whitish vein, 1 inch thick, probably quartz, strikes N. 10°–15° W. Rusty stain, 4 to 8 inches thick, occurs on some of the sheet surfaces. The top sheets are cream colored from a slight general discoloration. (See p. 56.)

The plant consists of 7 derricks, 3 hoisting engines, an air compressor (capacity 210 cubic feet of air per minute), 2 large drills, and 12 air plug drills.

Transportation is by a siding from the Boston and Maine Railroad, as shown on map (fig. 21). Seven-eighths of the product consists of paving, curbing, flagging, and crossings, the remainder being dimension stone and bases for monuments. Its markets are chiefly Boston, Albany, and their vicinities.

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The Pease quarry is in South Milford, about 1½ miles S. 25° W. of Milford village, on the 350 feet level, on the same hill the Lovejoy and Kittredge quarries are on. (See fig. 21.) Operator, Milford Quarry and Construction Company, Milford, N. H.

The granite in the east half of the quarry is a quartz monzonite of light-gray shade (with very slight bluish tinge apparent only in large masses of the stone) and spangled with black mica. Its texture is fine, inclining to medium, with feldspar and mica up to 0.2 inch. Its constituents are identical with those of specimen 50, b, from the Kittredge quarry, page 161.

The granite from the west half of the quarry (specimen D, XXVIII, 64, a), "pink stock," is a quartz monzonite of light buff-gray color spangled with black mica. Its texture is even grained, fine, inclining to medium, with feldspar and mica up to 0.2 inch. Its constituents, in descending order of abundance, are: Light smoky quartz with cavities in sheets, many parallel; colorless, transparent to milk-white soda-lime feldspar (oligoclase); light buff-gray potash feldspar (microcline); both feldspars are somewhat kaolinized and micacized; and biotite (black mica), some of it chloritized. Accessory minerals are: Magnetite, apatite, and zircon. Secondary: Kaolin, white micas, chlorite, and carbonate. It effervesces slightly with cold dilute muriatic acid.

This is a constructional granite of warm tint with conspicuous small black micas.

The quarry, opened in 1886, measures about 600 feet east-west by 400 and 300 feet from north to south, and from 35 to 60 feet in depth.

The sheets are lenticular, from 2 to 22 feet thick, and have a slight northerly dip. There are 2 sets of joints: Set A, striking N. 15° E., vertical, and spaced 50 to 200 feet, forms headings on west wall and 200 feet east of it next to the dikes. Set B, striking N. 80° W. and dipping 75° south, is spaced 5 to 50 feet and occurs on north and south walls. The rift is reported as horizontal and the grain as vertical with N. 65° W. course. A flow structure, shown by biotitic bands, alternating with more feldspathic and quartzose ones, strikes N. 70°–75° W., and dips 25° south. This is conspicuous on the south side but at the southwest corner, where the granite is overlain by a gneiss as shown in fig. 5 (p. 63), the flow structure has a N. 70°–75° E. course and dips 20°–25° S. The strike of the gneiss is N. 75° W. and the dip 20° S. This gneiss consists of light-gray to milk-white soda-lime feldspar (oligoclase), smoky quartz, biotite, with magnetite, apatite, and zircon. It is thus a mica diorite gneiss. There are 2 basic dikes striking N. 15° E. and vertical, one, 4 feet thick, makes the west wall; the other, 12 to 18 inches thick, forms a jog 200 feet east of it. Within 50 feet of the thicker dike the granite passes from a light buff gray to a medium pinkish gray, owing to the darkening of the feldspars and to hematitic stain. These dikes are

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also the probable cause of the difference between the color of the granite in the western and eastern halves of the quarry, the amount of hematitic stain increasing with the nearness of the dikes. (See pp. 36, 55.) A 4-inch pegmatite dike strikes N. 65° W. and consists of quartz, white feldspar, and biotite, the particles being up to 2 inches in diameter. Limonitic stain up to 2 inches thick occurs on some sheets only.

The plant consists of 4 derricks (2 with a capacity of 25 tons), 3 hoisting engines, an air compressor (capacity 345 cubic feet of air per minute), a large drill, 12 air plug drills, 2 surfacers, and a steam pump.

Transportation is effected, as shown on the map (fig. 21), by a siding from the Boston and Maine Railroad.

The product is used for bridges and buildings and the waste for paving. Specimen building of "pink stock:" Thayer Memorial Library at Franklin, Mass Contracts in 1906: Neponset, Mass., railroad bridge; piers 12, 25, 26, and 32 on the Prison Point Street bridge (Boston and Maine Railroad), East Cambridge, Mass.; and east side coping of the Atlantic Avenue Bridge, Boston.

The Tonella old quarry is in South Milford, 1½ miles south of Milford village. (See fig. 21.) Operators, Tonella & Sons, Milford, N. H.

The granite (specimens D, XXVIII, 54, a, b) is a quartz monzonite of light-gray shade (without either bluish or greenish tinge), with very minute black spangles.

Its texture is fine, even grained, with feldspars up to 0.15 inch, and black mica in slender scales but exceptionally over 0.1 inch. Its constituents, in descending order of abundance, are: Very light smoky quartz with hairlike crystals, probably of rutile, and cavities in sheets; colorless clear to milk-white soda-lime feldspar (oligoclase) slightly kaolinized and micacized; very light gray potash feldspar (microcline and orthoclase), mostly intergrown with quartz circular in cross section, and in some cases very slightly kaolinized; and biotite (black mica), some of it chloritized. Accessory minerals are: Magnetite, zircon, allanite, apatite, and rutile. No pyrite detected. Secondary: Kaolin, chlorite, and 2 white micas.

An estimate of the mineral percentages, made by applying the Rosiwal method to a camera lucida drawing of a thin section enlarged 40 diameters, yields the following results with a mesh of 1.7 inches and a total linear length of 42 inches.

Estimated mineral percentages in Milford, N. H., granite from the old Tonella quarry.

Quartz	36.76
Soda-lime feldspar (oligoclase)	29.16
Potash feldspars (microcline 14.00, orthoclase 13.58)	27.58
Black mica	6.50
	100.00

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The average diameter of the particles obtained by the same method is 0.011 inch.

This is a fine-grained monumental granite, in shade a trifle lighter than Hallowell, Me., granite, but not as light as that of North Jay, Me. It takes a high polish. The only contrast, visible but a few feet off, is between the black mica and the combined quartz and feldspars. The polished face shows many minute particles of magnetite.

The quarry, opened in 1900, measures about 300 feet north-south by 100 feet across and from 20 to 35 feet in depth.

The sheets, from 2 to 14 feet thick, are lenticular horizontal and regular. There are 2 sets of joints: Set A, striking N. 85° W. and vertical or dipping steep south, is spaced 20 to 50 feet, and forms a heading 3 feet wide, 125 feet from the south end. Set B, striking N. 35–40° E. and vertical, is intermittent and confined to upper sheets. It forms a heading on the east wall, and recurs 30 feet from west wall. From the large blocks of gneiss attached to granite lying on the dumps and from the occurrence of this gneiss in a much weathered condition in or under the drift on the edge of the quarry, it is evident that the rock surface originally included a mass of gneiss which either capped the granite or formed a large inclusion in its upper part. This gneiss is coarse, biotitic, with lenses of pinkish potash feldspar (microcline) bordered with clear to milk white-soda-lime feldspar (oligoclase). Its quartz is smoky. Its accessory minerals are: Pyrite, magnetite, allanite, and zircon. The rift is reported as horizontal, and the grain as vertical with N. 85° W. course. There are no dikes, veins, or knots. Rusty stain occurs only along the headings, where it is 6 inches thick. The original rock surface was covered with 10 to 20 feet of till. This quarry is remarkably free from the common structural difficulties.

The plant, including cutting machinery at the village, comprises a derrick (with a mast of Georgia pine 105 feet high), a smaller derrick, 2 hoisting engines, an air compressor (capacity 108 cubic feet of air per minute), a large drill, an air plug drill, 18 air hand tools, a surfacer, and a steam pump.

Transportation is effected by cartage of one-half mile to railroad for rough stock, but of 2 miles to the cutting shed for blocks to be finished.

The product is used principally for monuments and the waste for paving. The firm makes a specialty of fine carved work, most of which finds a market in the West. Specimen: The Morgenthaler monument in Greenwood Cemetery, Hamilton, Ohio. This is a 5-ton block, 6 feet high, with a delicately carved branching ivy vine entwined about a cross, all in high relief on a roughly chipped face. As only ordinary hand tools were used the outlines in this are sharper than they would have been with the use of pneumatic tools.

The Tonella new quarry is 2¼ miles S. 25° W. of Milford village. (See fig. 21.) Operator, Tonella & Sons, Milford, N. H.

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The granite (specimen D, XXVIII, 55, a) is a quartz monzonite of medium buff-gray shade, spangled with fine black mica. Its texture is generally even-grained and fine, with feldspar up to 0.2 and mica to 0.1 inch, but with rare porphyritic light pinkish feldspars an inch in diameter. Its constituents, in descending order of abundance, are: Light amethystine to pale smoky quartz; colorless, clear to milk-white soda-lime feldspar (oligoclase), partly kaolinized and micacized; light-buff to cream-colored potash feldspar (microcline much intergrown with quartz circular in cross section); and black mica, some of it chloritized. Accessory minerals are: Magnetite, allanite, apatite, and zircon. Secondary: Kaolin, a white mica, chlorite, hematite from magnetite, and limonite from allanite.

In general color this rock resembles specimen 64, a, of the Pease quarry (p. 163), but its mica scales are finer. It may become pinkish as the excavation deepens.

A finer granite (specimen D, XXVIII, 55, c) from the upper part of the quarry is also a quartz monzonite of medium buff-gray color, spangled with extremely fine mica. Its texture is even grained, very fine, with feldspars up to 0.1 and mica rarely over 0.05 inch. Its constituents and stain are the same as the other.

A pinkish granite (specimen D, XXVIII, 55, d) occurring next to the dike described beyond, is of pinkish medium-gray color, like that adjoining the dike in the Pease quarry (p. 163), but its general texture is fine, with feldspars and mica up to 0.15 inch, and with sparse porphyritic feldspars from 0.02 to 0.04 inch. Its constituents, in descending order of abundance, are: Pale amethystine to light smoky quartz with hairlike crystals, probably of rutile, and cavities in two sets of sheets intersecting at right angles with rift and grain cracks parallel to them; a translucent to opaque pinkish soda-lime feldspar (oligoclase) partly kaolinized and micacized, the kaolinized parts showing hematite by incident light; pinkish potash feldspar (microcline and orthoclase, in twins), intergrown with quartz circular in cross section; biotite (black mica), some of it chloritized. Accessory minerals are: Magnetite, allanite, zircon, apatite, and rutile. Secondary: Kaolin, a white mica, carbonate, and hematite. It effervesces slightly with dilute muriatic acid.

The quarry, opened in 1905, measures 100 feet north-south by 80 feet across and has an average depth of 20 feet.

The sheets, from 18 inches to 6 feet thick, are lenticular and horizontal, or dip as high as 20° E. Only one set of joints occurs, striking N. 30° W., dipping 35° W., and spaced 5 to 20 feet. The granite is capped on the east and west sides by about 5 feet of coarse biotite gneiss, but on the west this is overlapped by 2 to 3 feet of granite, and hence the gneiss may be merely a large inclusion. This gneiss (specimen D, XXVIII, 55, b) consists of pinkish potash feldspar (micro-

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cline), and milk-white soda-lime feldspar, both intergrown with quartz; smoky quartz with cavities in sheets; and biotite. The accessory minerals are magnetite, zircon, apatite, and allanite. The foliation of the gneiss strikes about N. 45° W. The rift is reported as horizontal and grain as vertical, with N. 80° W. course. A flow structure shown by more biotitic streaks and planes strikes north and dips 20° W. At the top there is a band of fine-grained granite, 2 feet thick, in the flow direction. On the south side a vertical dike 2 feet 6 inches thick of augite camptonite strikes N. 10° E. This consists of soda-lime feldspar (andesine), augite, brown hornblende, magnetite in octahedra and skeleton crystals, apatite in slender prisms all through the feldspar, and pyrite, together with secondary chlorite and carbonate from alteration of augite. The granite for a thickness of 8 feet on the south side of this dike has a marked pinkish color, already shown under specimen 55, d (p. 166), as due to the presence of a very small amount of hematite.

The plant consists of 2 derricks and a hoisting engine.

Transportation involves cartage of one-fourth mile to a railroad siding, but of 2½ miles to cutting shed.

The product in 1906 had not yet been put upon the market pending further excavations.

The Comolli quarry is 3½ miles southwest of Milford village, at the east foot of Badger Hill, S. 10° W. of Burns Hill. (See fig. 21.) Operator, Comolli Brothers & Co., Milford, N. H.

The granite (specimen D, XXVIII, 58, a) is a quartz monzonite of light, inclining to medium, bluish gray color, and of very fine, even-grained texture, with feldspars and mica up to 0.1 inch. Its constituents, in descending order of abundance, are: Light smoky quartz with hairlike crystals, probably of rutile, and with cavities; bluish milk-white soda-lime feldspar (oligoclase), partly kaolinized; colorless clear potash feldspar (microcline and orthoclase) much intergrown with quartz circular in cross section; and biotite (black mica), some of it chloritized. Accessory minerals are: Magnetite, zircon, apatite, and rutile. Secondary: Kaolin and chlorite. It effervesces slightly with dilute muriatic acid.

This stone is so fine grained as to afford no contrasts except under close inspection, when only that between the mica and the general bluish gray of the rest appears. It is a monumental granite.

The quarry, opened in 1905, is about 70 by 50 feet and 5 to 15 feet deep.

The sheets, from 6 inches to 6 feet 6 inches thick, are lenticular and irregular. There are 2 sets of joints: Set A strikes N. 10° E. and dips 45° E. Set B strikes N. 80° W., is about vertical, and occurs at the south end. At the southeast corner the granite is overlain by 6 feet of coarse biotite gneiss. The rift is reported as horizontal and the

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grain as vertical with N. 80° W. course. A pegmatite dike strikes N. 75° E. The amount of rusty stain on sheets is insignificant.

The plant consists of 2 horse derricks and 12 air hand tools at the cutting shed at Milford, where compressed air is obtained from another plant.

Transportation involves cartage of about 4½ miles to the cutting shed.

The product is used entirely for monuments.

The Paradis quarry is on the Milford and Brookline township line, 3¾ miles S. 35° W. of Milford village and about one-half mile southeast of Badger Hill. (See fig. 21.) Operator, Milford Nashua Lake Street Granite Company, Milford, N. H.

The granite is a quartz monzonite of light inclining to medium bluish gray color, and very fine, even-grained texture, identical with that of the Comolli quarry, three-tenths mile north of it, described on page 167.

The quarry, opened in 1905, is about 150 by 72 feet and is 4 feet deep.

The sheets, from 2 to 7 feet thick, are lenticular and undulating. There are 2 sets of joints: Set A, striking N. 60° E. and vertical or dipping steeply south, is spaced 4 to 30 feet. Set B, striking north and vertical, forms the east wall only. The rift is reported as horizontal and the grain as vertical north-south. Pegmatite dikes, from 1 to 12 inches thick, strike N. 20° E. and dip 40° W., also N. 25° W. and vertical, but turning to N. 50° W. Rusty stain is 6 inches thick.

The plant consists of 2 horse derricks and 1 hand derrick.

The product is used for monuments and curbing, the former in Boston, the latter in Nashua, N. H.

The Souhegan quarry is 2½ miles S. 12° E. from Milford village and three-fifths mile southwest of Federal Hill. (See fig. 21.) Operator, The Daniels Granite Company, Milford, N. H.

The granite (specimens D, XXVIII, 53, a, b, c) is a quartz monzonite of dark gray shade with very slight pinkish tinge and very fine scales of black mica. Its texture is even grained and fine, with feldspar and mica not over 0.1 inch. Its constituents, in descending order of abundance, are: Light smoky quartz with few cavities, some in sheets; milk-white soda-lime feldspar (oligoclase), slightly kaolinized and micacized; colorless to dull greenish gray potash feldspar (microcline), intergrown with quartz circular in cross section, and biotite (black mica), some of it chloritized. Accessory minerals are: Magnetite, pyrite, apatite, allanite, and zircon. Secondary: Kaolin, a white mica, chlorite, carbonate, and some irregularly disseminated hematite stain which gives the pinkish hue.

Mr. George Steiger, of the United States Geological Survey chemical laboratory, finds that this granite contains 0.26 per cent of CaO (lime)

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soluble in hot dilute acetic acid, which indicates a content of 0.46 per cent of $CaCO_3$ (lime carbonate), the presence of which carbonate is also shown by the microscope and by a slight effervescence in cold dilute muriatic acid.

The stone takes a high polish and offers quite a contrast of shade between its hammered and polished faces. The polished surface shows rare particles of pyrite along with the usual abundance of magnetite particles. The only contrast between its minerals, that between the black mica and the general color of quartz and feldspar, is visible but a few feet off.

The quarry, opened in 1896, measures 150 by 50 feet and is 10 to 25 feet in depth.

The sheets, generally normal and from 6 inches to 5 feet thick, dip low west and south, but are intersected by sharply curved planes, "toe nails." There are two sets of joints: Set A, striking N. 80° W. and vertical, occurs only in the southern part. Set B, striking N. 22° E. and vertical, forms headings on the east and west walls, and recurs discontinuously at intervals of 10 feet. There is a rhomb-shaped inclusion at the south end, about 3 feet 6 inches across, of very coarse biotite gneiss, consisting of milk-white soda-lime feldspar (oligoclase-andesine), smoky quartz, and biotite, with a little copper pyrite. There is some banding in the granite parallel to the surface of the inclusion. (See p. 19.) The rift is reported as in places horizontal but generally dipping south at a very low angle, and the grain as vertical with N. 70° W. course. A pegmatite dike, up to 2 inches thick, with a little magnetite, strikes N. 30° E. and dips 50° W. Rusty stain on the sheet surfaces measures up to 6 inches.

The plant, including that of the cutting shed at Milford, comprises 5 derricks, a hoisting engine, a 12-ton traveling crane, an air compressor (capacity 100 cubic feet of air per minute), several air hand tools, 2 polishers, a steam drill, and a steam pump.

Transportation is by cartage of 3 miles to cutting shed on siding of Boston and Maine Railroad.

The product is used for monuments. Specimens: Seaver monument in cemetery at Brookline, N. H.; Captain Randall monument in Riverside Cemetery, Milford, N. H.

The Hayden quarry is 1¾ miles S. 25° E. of Milford village, over one-half mile N. 35° W. from Federal Hill. (See fig. 21.) Operator, Henry W. Hayden, Milford, N. H.

The granite (specimens D, XXVIII, 57, a, c) is a quartz monzonite of dark medium-bluish gray color with very fine black mica. Its texture is even grained, fine, with feldspar and mica up to 0.1 inch, but with rare porphyritic feldspars 0.2 inch. Its constituents, in descending order of abundance, are: Very light smoky quartz, some of it with cavities up to 0.03 millimeter in sheets; milk-white soda-

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lime feldspar (oligoclase), partly kaolinized and micacized; bluish translucent potash feldspar (microcline); and biotite (black mica), some of it chloritized. Accessory minerals are: Magnetite, pyrite, apatite, allanite, and zircon. Secondary: Kaolin, white micas, chlorite, and carbonate. Both feldspars are intergrown with quartz circular in cross section.

The stone takes a good polish. The polished face shows many fine particles of magnetite and rare ones of pyrite. The only contrast, that between the mica and the rest of the stone, is not visible at a distance.

The quarry measures about 150 feet N. 30° E. by 60 feet across and 15 to 20 feet in depth.

The sheets, from 4 inches to 5 feet thick, dip 10° S. 70° W. There are two sets of joints: Set A, striking N. 30° E. and vertical, is spaced 15 to 40 feet, and forms three 5-foot headings near the middle and on east and west sides. Set B, striking N. 60° W. and vertical, is spaced 20 to 30 feet. The rift is reported as dipping like the sheets and the grain as vertical with N. 60° W. course. In a part of the quarry the lower sheets are affected by short parallel fractures one-half to 1 inch apart. This resembles "shake" structure, but is much coarser. These incipient sheets seem to be due to some local strain. About 200 feet east of the quarry the granite is in contact with a coarse gneiss with a foliation striking east-west. Meandering pegmatite dikes, from one-fourth inch to 2 inches thick, in groups numbering up to 12, strike N. 50° W., with vertical or steep southeast dip, and recur at intervals of 20 to 30 feet. Another set of these dikes strikes nearly at right angles to the first. The pegmatite consists of cream-colored oligoclase, light smoky quartz with cavities in sheets, a little microcline, black mica, and magnetite, together with accessory pyrite, apatite, allanite, and zircon. Muscovite veins ("sand streaks") strike N. 60° W. at intervals of 1 to 12 inches near the pegmatite dikes. The granite contains here and there porphyritic crystals of biotite (black mica) up to 2 inches by 0.4 inch, with their flat and very thin sides parallel to the rift. (See p. 57.) Rusty stain on the sheet surfaces is from 2 to 6 inches thick. Pyrite occurs on the joint faces.

The plant comprises 2 derricks, a hoisting engine, and a steam pump.

Transportation is by cartage of 1¾ miles to Milford.

The product is dimension stone, blocks for monuments, and paving. The quarry is worked only from April to December of each year.

The Young quarry is 1¼ miles southeast of Milford village and three-fourths mile southwest of East Milford, or Laurel post-office. (See fig. 21.) Operators, Youngs Sons & Co., Milford, N. H.

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The granite (specimens D, XXVIII, 52, aa, c), "dark-blue New Westerly," is a quartz monzonite of general dark-gray shade (neither bluish, greenish, nor pinkish, but of smoke color) with very fine black spangles. Its texture is even-grained and fine, with feldspar up to 0.1—rarely 0.15—inch, and mica to 0.1 inch. Its constituents are, in descending order of abundance: Very light smoky quartz with cavities; slightly greenish-gray soda-lime feldspar (oligoclase), somewhat kaolinized and micacized; clear, colorless to grayish potash feldspar (microcline and orthoclase), very slightly kaolinized; and black mica, some of it chloritized. Accessory minerals are: Magnetite, pyrite, apatite, allanite, and zircon; secondary: White mica, kaolin, chlorite, carbonate, and a little hematite and limonite stain, the latter about the allanite.

An estimate of the mineral percentages obtained by applying the Rosiwal method to a camera lucida drawing of part of a thin section enlarged 40 diameters yields these results with a mesh of 2 inches and a total linear length of 34 inches.

Estimated mineral percentages in Milford, N. H., granite from the Young quarry.

Quartz	27.40
Soda-lime feldspar (oligoclase)	27.70
Potash feldspars (microcline 12.87, orthoclase 17.41)	29.28
Black mica (biotite)	13.51
Magnetite	.11
Allanite	1.00
(Accessory, 1.11.)	
	100.00

The percentages of magnetite and allanite are not perfectly reliable, for a slight shifting of the mesh would have changed the figures for one or both, but as representing together the accessories they are not far from the truth. The average diameter of all the particles, by the same method, is 0.0084 inch.

Mr. W. T. Schaller, of the United States Geological Survey chemical laboratory, finds that this granite contains 0.18 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates a content of 0.32 per cent of $CaCO_3$ (lime carbonate), the presence of which carbonate is also shown by the microscope and by a very slight effervescence with cold dilute muriatic acid.

A crushing test, made for the firm by Professor Ricketts, of the Rensselaer Polytechnic Institute, at Troy, N. Y., is reported as showing an ultimate crushing strength of 24,950 pounds to the square inch.

The stone takes a fine polish. The polished face shows some magnetite and a little pyrite. There is much contrast of shade between the hammered and the rough or polished face, the hammered

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face being light, slightly bluish gray. The contrast between the minerals, only visible near to them, is that between the black mica and the general color of the others.

The quarry, opened in 1886, a plan of which is shown in fig. 22, has a length of 370 feet, a width of 75 to 100 feet, and an average depth of 50 feet. Only the northwest bend was being worked in 1906.

The sheets, from 2 to 10 feet thick, are lenticular and generally horizontal. Joint courses are given in fig. 22. Set A is vertical, forms a heading at the west end, shown in Pl. VI, *B*, and recurs 70 feet east only. Set B dips 40° north, is spaced 5 to 10 feet, and occurs only at the northwest corner. The rift is reported as horizontal, but with a slight inclination to the west. There is no perceptible grain. Flow structure, shown by biotitic streaks, strikes N. 15° E. and dips 45° west. The marked feature of this quarry is the recurrence, at intervals of 20 feet, of dikes of pegmatite and aplite, already described on page 48 and shown in Pl. VI, *B*. These dikes are from one-fourth inch to 3 inches thick, occur in sets of three to eight, with a N. 25° W. course and a vertical dip. A few strike N. 25° E. and dip 40° ESE. They consist of cream-colored oligoclase, smoky quartz, cream-colored or pink microcline, and biotite, with magnetite, allanite, and zircon. The biotite crystals measure up to 2 inches in length. Rusty stain measures up to 8 inches on sheet surfaces. Joints A are coated with pyrite, which has mostly passed into limonite.

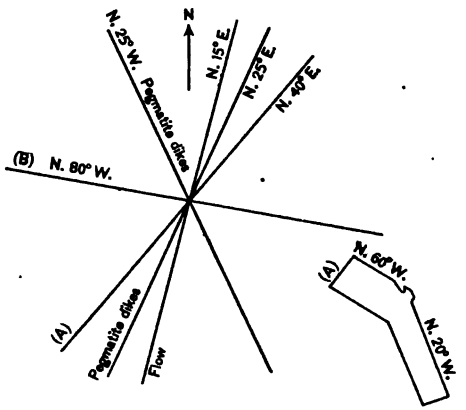

FIG. 22.—Structure and plan of Young quarry, Milford, N. H.

The plant, including that of the cutting shed, comprises 4 derricks, a hoisting engine, an air compressor run by a 22-horsepower gasoline engine, 2 steam drills, 12 air hand tools, and a steam pump.

Transportation is by cartage of three-fourths mile to the cutting shed, on the Boston and Maine Railroad, although a siding extends to within a few hundred feet of the quarry.

The product is used for monuments, the stained and veined parts and small sheets for paving. The monuments go mostly to Troy, N. Y. Specimens: The Senator E. Murphy and W. Fitzpatrick monuments at St. Mary's Cemetery; the Mrs. R. J. Stark monument at Oakwood Cemetery, Troy, N. Y.; the Mrs. J. Craig monument at Rural Cemetery, Albany, N. Y.

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The Milford Granite Company's quarries are a mile southeast of Milford village and 130 feet above it, on the east side of a hill. (See fig. 21.) The quarries were idle in 1906. Address, H. H. Barber, Milford, N. H.

The granite generally is like that of the Young quarry, described on page 171.

The quarries comprise 2 openings, along a N. 20° E. line. The southern opening is about 120 feet N. 20° E. by 60 feet across and is 40 feet deep. The northern opening, separated from the other by an interval of 150 feet, is about 900 feet N. 20° E. by 50 to 75 feet across and from 10 to 30 feet deep.

The sheets, from 1 to 5 feet thick, are lenticular and horizontal. Joints, striking N. 10° to 30° E. and vertical, are spaced 1 to 5 feet and form headings on the east and west walls of both quarries and also in the middle of southern one. Some of the joints of these headings are "sand seams," or veins up to one-half inch thick of a central band of quartz crystals with borders of muscovite. (See p. 51.) The granite of the west wall of both quarries is overlain by a mass of many-colored banded gneiss, 12 to 16 feet thick, with a foliation striking about N. 75° W. and dipping 75° south, with injections of pegmatite starting at the contact and tapering out within the gneiss. (See Pl. VI, *A*.) There is much variety in the composition and texture of the gneiss. The quartz of the finer augite-diorite gneiss has cavities, up to 0.047 millimeter, which are in sheets intersecting at right angles. The granite on either side of the muscovite veins in the heading is much reddened for half an inch; the biotite is mostly chloritized, the oligoclase is much kaolinized and micacized, and much limonite and hematite stain proceeds from particles of magnetite and pyrite.

The plant comprises, at the quarries, 4 derricks (6 to 20 tons), 2 hoisting engines, a steam drill, and a steam pump. At the cutting shed are a 45-horsepower engine, an air compressor (capacity, 212 cubic feet air per minute), a crane (capacity, 20 tons), a surfacer, and 2 polishers.

Transportation involves cartage of half a mile to a cutting shed on the Boston and Maine Railroad.

The New Westerly quarry is 2¼ miles northwest of Milford village. (See fig. 21.) Operator, New Westerly Granite Company, Milford, N. H.

The granite (specimens D, XXVIII, 60, a, b), "New Westerly blue," is a quartz monzonite of medium slightly bluish-gray color, spangled with fine black mica. Its texture is even-grained, fine, inclining to medium, with feldspar and mica up to 0.2 inch and a marked parallelism in the mica scales. Its constituents, in descending order of abundance, are: Light smoky quartz with cavities up to 0.008 millimeter in sheets; slightly greenish-blue soda-lime feldspar

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(oligoclase), partly kaolinized and micacized; slightly pinkish-gray potash feldspar (microcline, some twinned); biotite (black mica) some of it chloritized. Both feldspars are intergrown with quartz. Accessory minerals are: Magnetite, pyrite, allanite, apatite, and zircon; secondary: Kaolin, 2 white micas, chlorite, hematite, and carbonate.

An estimate of the mineral percentages, obtained by applying the Rosiwal method to a camera lucida drawing of part of a thin section, enlarged 40 diameters, yields the following results with a mesh of 1½ inches and a total linear length of 34.5 inches:

Estimated mineral percentages in Milford, N. H., granite from the New Westerly quarry.

Quartz	17.10
Soda-lime feldspar (oligoclase)	45.22
Potash feldspars (microcline 15.59; orthoclase 15.71)	31.30
Black mica (biotite)	5.74
Magnetite	.64
	100.00

The average diameter of all the particles, obtained by the same method is 0.009 inch.

Mr. George Steiger, chemist, of the United States Geological Survey, finds that this granite contains 0.12 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates a content of 0.21 per cent of $CaCO_3$ (lime carbonate), the presence of which carbonate is shown by the microscope and by a slight effervescence with cold dilute muriatic acid.

The stone takes a high polish, which brings out the greenish and reddish tints and darkens the shade so that the general color becomes a medium greenish gray. The polished face shows a few grains of magnetite and rare ones of pyrite.

The quarry, opened in 1876, is about 150 feet from east to west by 100 feet across and from 15 to 65 feet in depth.

The sheets, from 6 inches to 30 feet thick, increasing in thickness downward, dip south at a low angle. There are 2 sets of joints: Set A, striking N. 10° E., dipping 60° E. and 90°, is spaced 3 to 50 feet and forms a heading on east side. Set B, striking N. 75°–80° W. and vertical, is spaced 30 to 40 feet and forms a heading on the south side. The rift is reported as horizontal and the grain as vertical with a N. 80° W. course, but it is so feeble that the stone can be split almost as well across it.

The plant, including that of the cutting shed, comprises 3 derricks, 3 hoisting engines, 3 air compressors (capacity of two being 140 and 177 cubic feet of air per minute, the third one requires a 22-horsepower engine to run it), 2 large drills, 5 air plug drills, a surfacer, 16 air hand tools, a polisher, and 2 steam pumps.

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Transportation requires cartage of about 2¾ miles to the cutting shed and railroad at Milford.

The product is used for monuments.

The Carlton quarry is 2 miles northwest of Milford village. (See fig. 21.) Operator, A. E. Carlton, Milford, N. H.

The granite (specimen D, XXVIII, 61, a) appears to be also a quartz monzonite, but probably with more of the potash feldspar. Its shade is medium pinkish gray, spangled with black. Its texture is porphyritic; the groundmass is fine, with feldspar and mica up to 0.1 inch and the isolated feldspars up to 0.4 and exceptionally 1 inch. Its constituents, in descending order of abundance, are: Light smoky quartz with hairlike crystals, probably of rutile, and cavities in sheets, with rift cracks parallel to them; light pinkish-gray potash feldspar (microcline), intergrown with quartz circular in cross section, inclosing particles of soda-lime feldspar, and somewhat kaolinized and micacized, making up part of the groundmass and also the porphyritic crystals; in almost equal amount a milk-white soda-lime feldspar (oligoclase), somewhat kaolinized, micacized, and intergrown with quartz; and biotite (black mica), some of it chloritized. Accessory minerals are: Magnetite, apatite, allanite, and rutile; secondary: Kaolin, 2 white micas, chlorite, and hematite.

At the north corner of the quarry there is a band of quartz monzonite of medium slightly bluish-gray color, with fine black mica, like the stone of the New Westerly quarry described on page 173.

The chief product of this quarry differs from all the other Milford, N. H., granites by its marked porphyritic texture. It is a constructional granite.

The quarry, opened in 1881, is about 110 by 100 feet and averages 30 feet in depth.

The sheets, from 1 to 16 feet thick, dip west at a low angle. There are 2 sets of joints: Set A, striking N. 50° W. and about vertical, is spaced 20 to 60 feet and forms a heading on the west side and the east wall. Set B, diagonal, striking north, and dipping 75° east, forms but one joint. The rift is reported as slightly inclined to the west and the grain as dipping 70° N. Flow structure, shown by streaks of black mica, also by the band of fine granite, strikes N. 70° E. and dips 40° to 50° N. 20° W. Rusty stain is up to 8 inches thick.

The plant consists of a horse derrick and a hand derrick, a steam drill, and an air compressor with a capacity of 50 cubic feet of air per minute.

Transportation is by cartage of 2 miles to Milford.

The product is mostly for street work in Boston and Cambridge. Specimen monument: The Abbie H. Patten monument, North Cemetery, Milford, N. H.

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The Bishop quarry is about 1¼ miles northwest of Milford village. (See fig. 21.) Operator, John B. Bishop, Milford, N. H.

The granite (specimen D, XXVIII, 62, a) is a quartz monzonite of light-gray shade and faintly cream colored, with exceedingly minute black spangles. Its texture is even grained, fine, with feldspars and micas very rarely exceeding 0.1 inch. The mica plates measure much less than this in width. Its constituents, in descending order of abundance, are: Clear to pale smoky quartz with hairlike crystals, probably of rutile, and cavities in sheets; milk-white to cream-colored soda-lime feldspar (oligoclase) somewhat kaolinized and micacized; clear, colorless potash feldspar (microcline), in places very slightly kaolinized; biotite (black mica), some of it chloritized and either partially bleached or interleaved with muscovite. Both feldspars are intergrown with quartz. Accessory minerals are: Magnetite, apatite, and zircon. Secondary: Kaolin, 2 white micas, chlorite, and carbonate.

This stone resembles most closely in fineness that (specimen 54, a, b) of old Tonella quarry (p.164), and that (specimen 50, a) of the small band in Kittredge quarry (p. 162), but differs from both in tint. It ought, from the fineness of its mica, to take a high polish.

The quarry, opened about 1831, measures about 250 feet by 100 or 200 feet in width, and has an average depth of 25 feet.

The sheets, from 6 inches to 3 feet thick, are somewhat irregular and dip west and north at low angles. There are 2 sets of joints: Set A, striking N. 50° E. and vertical, is spaced 10 to 20 feet and forms a heading on the east side and west wall. Set B, striking N. 75°–80° W., seems to be consequent on the flow structure and is spaced very irregularly. Flow structure, shown by biotitic bands up to one-half inch wide and light bands up to 2 inches wide, strikes N. 75°–80° W., and dips 50° N. 10°–15° E., also 90°. There are angular inclusions, 3 inches in diameter, of very coarse gneiss, consisting of a pinkish and a cream-colored feldspar, smoky quartz, and biotite. In the eastern part of the quarry pegmatite dikes, up to 2 inches wide, strike N. 20° E. across the flow structure and dip about 90°. Their feldspars resemble those of the gneiss in color, and the quartz is smoky.

The plant consists of 5 horse derricks, an air compressor (capacity 69 cubic feet of air per minute), a large drill, 2 air plug drills, and a steam pump.

Transportation is by cartage of 1¾ miles to Milford.

The product is mostly curbing.

CONWAY.

Topography.—The Conway quarries are in Carroll County, N. H., near North Conway, some of them on the east and west sides of the Saco Valley. The Redstone quarries, on the east, are at the south foot of a series of summits ranging from 1,550 to 2,375 feet above sea

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level (Black Cap, Middle Mountain, and Rattlesnake Mountain), known collectively as the Green Hills, and the White Mountain quarry on the west is on a 765-foot lenticular granite mass lying about 2 miles S. 25°–45° E. of the granite domes known as White Horse and Cathedral ledges. Also belonging to this group of quarries is the Fletcher & Lahey quarry, in the town of Madison, which adjoins Conway on the south. This quarry lies southeast of Moat Mountain and about 2½ miles southwest of Conway Corners.

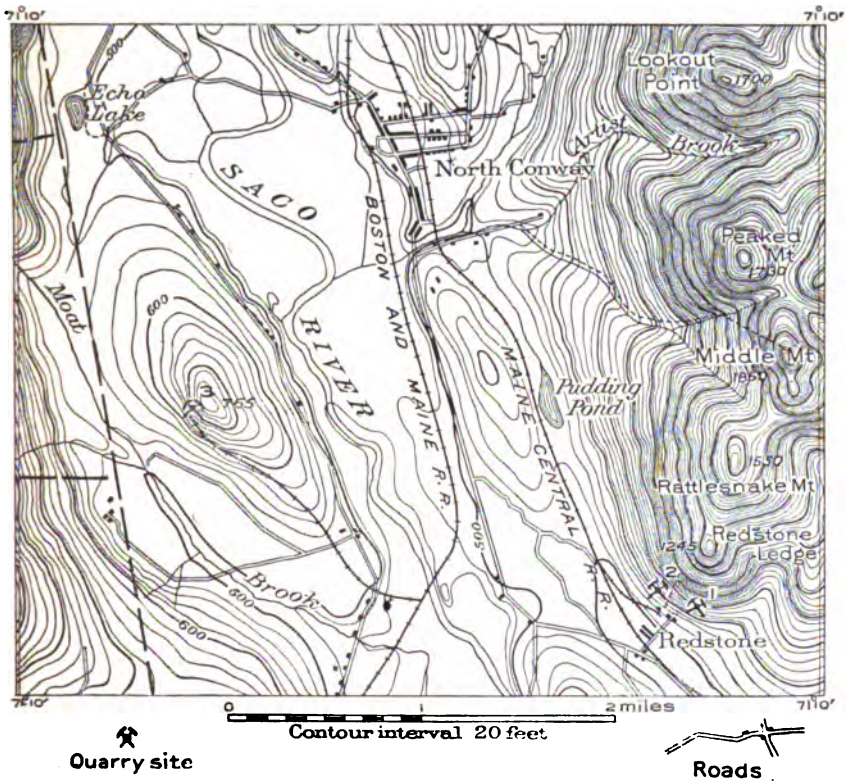

FIG. 23.—Map of part of Conway, N. H., showing locations of granite quarries. 1, Redstone red granite quarry, Maine and New Hampshire Granite Corporation. 2, Redstone green granite quarry of the same firm. 3, White Mountain quarry, Henry A. Hitners Son's Company, 1907. The boundary between pink and green granite is shown by dotted line.

Geology of the quarries.—The geological feature of general interest in Conway granites is their marked rift and grain and the manifest relation of these to the sheets of microscopic cavities, as shown in fig. 1 and described on page 42. The rift is reported as uniformly horizontal and the grain as vertical with N. 80°–90° W. course. Another feature is the contiguity of a yellowish-green biotite-hornblende granite to the pink biotite granite at Redstone (Pl. VII, *A*, and fig. 23). The writer attempted to trace the boundary between these two granites above the quarries, but found it impracticable

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without using much time, owing to the reddening of both granites at the surface by forest fires. However, between the 500 and 800 foot levels the boundary has a N. 23° E. course and is said to continue in that direction toward Rattlesnake Mountain. Although the feldspars of both these granites are equally kaolinized, their original colors probably differed as greatly as do their present ones. The feldspar of the green stone seems to have been a bluish gray and that of the pink probably clear and colorless or slightly pinkish. Their present colors are due to the formation of limonite in the green and hematite in the pink. This limonite is largely traceable to somewhat abundant allanite and to the hornblende, while the hematite may be attributed to the oxidation of magnetite or of ferrite in infinitesimal particles in the feldspars. These two granites side by side represent originally different materials, and the line of their contact indicates the direction of their flow. A 20- by 30-foot segregation or dike of porphyritic biotite-hornblende granite, and geodes, coated internally with calcite rhombs and chlorite, should also be noted as occurring at the red quarry. The joint systems at the four quarries have courses of N. 70°–90° W., N. 35° W., N. 15° E., and N. 30° E. As shown in Pl. VII, *A*, the sheets dip gently east and west from the axis of the ridge.

Description of Conway granites.—Conway granites are all coarse constructional granites, mostly of pinkish color mottled with amethystine gray and spotted with black; but one is dark yellow-greenish gray spotted with black. They are biotite or biotite-hornblende granites, and consist, in descending order of abundance, of: More or less pinkish potash feldspar (orthoclase), always minutely intergrown with soda-lime feldspar (oligoclase-albite); amethystine-smoky quartz; a little separate oligoclase-albite; and biotite (black mica) with or without a little hornblende. The accessory minerals are: Magnetite, (ilmenite?), pyrite, apatite, fluorite, zircon, and allanite (abundant in the green granite). The secondary are: Kaolin, chlorite, titanite (leucoxene), calcite, hematite, and limonite stain (the latter abundant in the green granite from which hematite is absent), and epidote.

Estimates of the mineral percentages, obtained by applying the Rosiwal method to 4 specimens from 3 quarries, yields the following results (see pp. 179, 180, 183, 185):

Estimated mineral percentages in Conway granites.

	Average.
Feldspar, 54.79 to 68.00	63.15
Quartz, 26.00 to 38.26	31.04
Mica, 4.20 to 6.95	5.81

Analyses of the red and green granites are quoted on pages 180. 183. They show 1 per cent more of iron oxides in the green. The estimates show 9.61 per cent more quartz in the green.

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A. REDSTONE LEDGE, CONWAY, N. H., LOOKING N. 30° E.

Showing, on the left, quarry in green granite and, on the right, one in pink granite; also the sheets dipping away from axis of hill. Boundary between the two granites runs diagonally up the hill. In foreground is stone crusher for waste.

B. STORAGE YARD AT MILFORD, MASS., WITH FINISHED BLOCKS OF MILFORD PINK GRANITE FOR THE PENNSYLVANIA RAILROAD TERMINAL AT NEW YORK.

Elevated rails are for traveling crane.

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The percentage of CaO (lime) soluble in hot dilute acetic acid in granites from two quarries was found by Messrs. Schaller and Steiger, chemists, of the United States Geological Survey, to average 0.205 per cent, and the $CaCO_3$ (lime carbonate) thus indicated to average 0.353 per cent.

A compression test of the Redstone pink shows it to have a compressive strength of 22.370 pounds per square inch. This test does not bear out the damaging judgment passed on Conway granites by Hawes in Hitchcock's Geology of New Hampshire,[a] although all very coarse granites weather more easily than those of finer grain.

The Conway quarries.—The Redstone red quarry is in the town of Conway, about 3 miles S. 35° E. of North Conway, on the base of Redstone Ledge, one-third mile N. 50° E. of Redstone station on the Maine Central Railroad, and 180 feet above it. (See North Conway, N. H., topographic sheet of the United States Geological Survey; also fig. 23 and Pl. VII, *A*.) Operator, Maine and New Hampshire Granite Corporation, Portland, Me.

The granite (specimens D, XXVIII, 35, a, b, j, k), "red granite," is a biotite granite of light pink color with large dark gray and small black spots. Its texture is even grained, coarse, and with feldspars up to 0.75 inch, exceptionally 1.25, and black mica up to 0.3 inch. Its constituents, in descending order of abundance, are: A light pink nearly opaque potash feldspar (orthoclase, mostly twinned) minutely intergrown with soda-lime feldspar; smoky-amethystine quartz with cavities, up to 0.012 millimeter, in sheets, intersecting at right angles and parallel to rift and grain cracks (see fig. 1 and p. 42); translucent, very light gray to milk-white striated soda-lime feldspar (oligoclase-albite); and biotite (black mica) with but little of it chloritized. The orthoclase is much kaolinized, the oligoclase less so. The orthoclase in places surrounds oligoclase; in one specimen a small crystal of orthoclase is inclosed by oligoclase and that has a zone of orthoclase about it. The accessory minerals are: Magnetite (ilmenite?), pyrite, apatite, fluorite, and zircon. The secondary: Kaolin, chlorite, titanite (leucoxene), calcite, and hematite stain mostly combined with the kaolin and only visible under incident light.

Estimates of the mineral percentages by the Rosiwal method yield the following results:

Estimated mineral percentages in Redstone, N. H., "red granite."

[Specimen cut at right angles to both rift and grain; mesh 0.8 inch, total linear length 39.2 inches.]

Feldspars	62.60
Quartz	31.00
Mica (biotite)	6.40
	100.00

[a] Vol. 3, pt. 4, p. 195.

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Estimated mineral percentages in Redstone, N. H., "red granite."

[Specimen cut parallel to rift showing larger feldspars; mesh 1.2 inches, total linear length 28.8 inches.]

Feldspars	68.00
Quartz	26.30
Mica (biotite)	5.70
	100.00

Average of both above estimates.

Feldspars	65.30
Quartz	28.65
Mica (biotite)	5.55

An analysis of this granite, made for the firm in 1898 by Franklin C. Robinson, State assayer of Maine, is here given merely for reference.

Analysis of "red granite" from Redstone, N. H.

SiO_2 (silica)	71.44
Al_2O_3 (alumina)	14.72
Fe_2O_3 (iron sesquioxide)	2.39
FeO (iron oxide)	.46
(Total iron oxides, 2.85.)	
MgO (magnesia)	.96
Na_2O (soda)	7.66
K_2O (potash)	.89
Rare elements, mostly TiO_2 and ZrO_2 (titanium and zirconium dioxides)	.78
Manganese, sulphur, calcium, phoshates	Traces.
Loss at red heat (mostly water)	.61
	99.91

Specific gravity 2.635.

Mr. W. T. Schaller, of the United States Geological Survey's chemical laboratory, finds that this granite contains 0.16 per cent of CaO (lime), soluble in hot dilute acetic acid, which indicates a content of 0.267 per cent of $CaCO_3$ (lime carbonate), the presence of which carbonate is also shown by the microscope.

A test made at the United States arsenal at Watertown, Mass., in 1887, gives this granite a compressive strength of 22,370 pounds per square inch.

The stone takes a high polish, but the large size of its mica scales is not favorable to the durability of the polish under long-continued outdoor exposure. Polished faces show some magnetite. As the relative amount of gray to pink feldspar is small the contrast is mostly between the pink feldspar and the smoky amethystine quartz, which is very pleasing. The minor spots of black mica give it still more character. This is a constructional granite, but is also, by its polish and contrasts, adapted to internal decorative uses.

The quarry, opened about 1887, is about 500 feet from east to west by 300 feet across and from 30 to 80 feet deep, with a working face 80 feet high on the north. (See Pl. VII, *A*.)

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The sheets, from 4 to 30 feet thick, are normal and arch across the axis of the hill, dipping 15° to the east in this quarry. There are 3 sets of joints: Set A, striking east-west and vertical, is spaced 5 to 40 feet, and not everywhere continuous. Set B, striking N. 35° W. and dipping 80° S., forms a heading in the west part but does not recur. Set C, striking N. 15° E. and vertical, recurs at 160 feet. The rift is reported as horizontal and the grain as vertical with east-west course. Both are marked and appear as delicate cracks in the quartz particles on polished surfaces parallel to the "hard-way." This interesting textural feature is fully discussed on page 42 and is illustrated in fig. 1. There are small dikes of deep pinkish aplite (fine textured, particles 0.185–0.555 millimeter) consisting of pinkish orthoclase, clear quartz, clear oligoclase, and very little biotite, with secondary muscovite and hematite stain. In the eastern part of quarry is a mass about 30 feet north to south by 20 feet east to west and with an exposed depth of 10 feet, which may be a very large knot or quite possibly the upper part of a dike oval in cross section. Streaks of black mica 10 feet long radiate from its upper surface; also irregular pegmatitic bands with small dark-gray knots. Its matrix (particles 0.074 to 0.59 millimeter) is of medium purplish-gray color with porphyritic, light-pinkish feldspars up to 0.7 inch, light smoky quartz to 0.03 inch, and black silicate to 0.2 inch. The matrix consists of orthoclase, quartz, oligoclase-albite, hornblende, and biotite, with accessory magnetite, apatite, fluorite, titanite, and zircon. The large feldspars are orthoclase with intergrown oligoclase and quartz. There are elliptical and spherical knots from one-half inch to 14 inches in diameter of exceedingly fine-grained, very dark gray, largely biotitic material with sparse porphyritic feldspars. Lenses of pegmatite up to 2 feet by 6 inches also occur, and lenticular geodes, mainly of intergrown quartz and feldspar surrounded by a half-inch band of aplite. These geodes are lined with crystals of smoky amethystine quartz and orthoclase incrusted with chlorite and calcite. Some obtuse rhombs of calcite are one-half inch wide. Joint C is coated with epidote and chlorite, and the granite for one-half inch back of it is much altered to kaolin and mica, and stained by hematite and limonite. (See p. 62.) Rusty stain is an inch thick along sheet surfaces, but up to 4 inches along the joints.

The plant, including also that of the adjacent quarry (p. 182) and of the cutting shed, comprises 12 derricks, 6 hoisting engines, 2 locomotive cranes, 2 air compressors (capacity 690 and 80 cubic feet of air per minute), a large drill, 8 air plug drills, 29 air hand tools, 2 surfacers, a lathe for stones 12 feet by 2 feet 6 inches, 2 polishing lathes for stones 22 feet by 4 feet and 15 feet by 2 feet 6 inches, 3 polishers, 2 stone crushers, and 3 stationary engines for crushers, lathes, and polishers.

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Transportation is by a gravity track 1,100 feet long from quarry to shed and by siding from there.

The product is used mainly for buildings. Specimens: First National Bank, Chicago; First and Fourth National banks, Cincinnati, with polished columns; Franklin Savings Bank, New York: Temple Bar Building, Brooklyn; Union station, Pittsburg; City hall, Lowell; High school, Springfield, Mass.; base of Longfellow monument, Portland, Me.; State Library, Concord, N. H. The pilasters and trimmings of this library are of Concord granite, the columns, at the entrance, are of polished green granite from the next quarry, and the rest is of the "red granite."

The Redstone green quarry is in the town of Conway, about 3 miles S. 25° E. of North Conway, on the base of Redstone Ledge, about 800 feet west-northwest of the red quarry, described above, less than one-half mile N. 15° E. from Redstone station and about 140 feet above it. (See fig. 23 and Pl. VII, *A*.) Operator, Maine and New Hampshire Granite Corporation, Portland, Me.

The granite (specimens D, XXVIII, 36, a, b, c), "green granite," is a biotite-hornblende granite of dark-yellow greenish-gray color with black spots. Its texture is even grained, coarse, with feldspars up to 0.8 inch and mica to 0.3 inch. Its constituents, in descending order of abundance, are: Medium-gray potash feldspar (orthoclase) with some yellow-green stained cleavage faces. (This feldspar is always minutely intergrown with lime-soda feldspar, oligoclase-albite, some of it is twinned and it is all much kaolinized); dark yellow-green smoky quartz with cavities in 2 or 3 sets of intersecting sheets with rift and grain cracks parallel to two of them and in places coinciding with them (see p. 42); very little separate soda-lime feldspar (oligoclase-albite), slightly micacized; biotite (black mica) and hornblende, some of it corroded. Accessory minerals are: Magnetite (ilmenite?), fluorite, allanite (mostly in biotite), and zircon. Secondary: Kaolin, a white mica, calcite, epidote in veinlets, chlorite, and limonite. There is a faint yellowish limonitic stain along the rift and grain cracks of the quartz, and along these and the cleavage planes of the feldspar, and along borders of all particles. This stain is deeper in the quartz because there are more cracks in it, and this, in combination with its original slightly amethystine hue, gives the quartz a greenish tint; and this yellow stain also, in connection with the original slightly bluish gray of the feldspars, gives them in places a greenish color. Much of this limonite stain comes from allanite particles, as shown in fig. 3, some also from the hornblende, biotite, and magnetite. (See p. 52.)

An estimate of the mineral percentages, obtained by the Rosiwal method, yields the following results with one-half inch mesh and total linear length of 71 inches:

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Estimated mineral percentages in "green granite" from Redstone, N. H.

Feldspar	54.79
Quartz	38.26
Mica (biotite)	6.95
	100.00

An analysis made for the firm by Franklin C. Robinson, State assayer of Maine, in 1899, is given here merely for reference:

Analysis of "green granite" from Redstone, N. H.

SiO_2 (silica)	70.42
Al_2O_3 (alumina)	14.64
Fe_2O_3 (iron sesquioxide)	1.54
FeO (iron oxide)	2.34
(Total iron oxides, 3.88.)	
MgO (magnesia)	1.20
Na_2O (soda)	7.80
K_2O (potash)	.71
Rare elements, mostly TiO_2 and ZrO_2 (titanium and zirconium dioxides)	.48
Manganese, sulphur, calcium, and phosphates	Traces.
Loss at red heat, mostly water	.61
	99.74

Specific gravity 2.634.

It will be noticed, on comparing the amounts of iron oxides in this and the red granite (p. 180), that this exceeds the other by 1 per cent, which is attributable to its larger content of hornblende and allanite and of the limonite proceeding therefrom.

When first quarried this stone is more greenish than after a few years' exposure, when its feldspars become more grayish, but its general color is even then still markedly greenish. The cause of this change is not apparent, for organic acids do not reach the quarried blocks. It takes a high polish, but its large-sized mica plates furnish vulnerable points of attack by the weather under prolonged exposure. The polished face shows a little magnetite. The contrasts are weaker than in the red granite, owing to the darker shade of its feldspar. Whether in the rough or polished, its color is striking. Though not unsuitable for purposes of construction, it is a coarse decorative granite well adapted for sheltered positions.

The quarry, opened about 1887, is about 150 feet north to south by 100 feet across and up to 50 feet in depth, which is the height of the working face on the north. It is worked at intervals only.

The sheets, from 11 inches to 14 feet thick, dip about 15° W. (See Pl. VII, *A*.) The joint sets are the same as in the red quarry, and the rift and grain are likewise the same.

The plant has been included in that of the red quarry.

Transportation is by cartage of 500 feet to the cutting shed.

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The product has been used for buildings and polished columns. Specimens: Front of the first three stories of Fidelity Mutual Life Insurance Building, Philadelphia; polished columns in the Northwestern Guarantee Loan Company's Building, Minneapolis; in the Baxter Building, on Congress street, Portland, Me., and in the upper and lower vestibules of the State Library, Concord, N. H.

The White Mountain quarry is in the town of Conway, 1¾ miles southwest of North Conway, on the west side of a hill between Saco River and Moat Brook, southeast of White Horse Ledge. (See fig. 23.) Owner, Henry A. Hitner's Sons Company, Pennsylvania Building, Philadelphia.

The granite (specimens D, XXVIII, 38, a, b) is a biotite granite of medium pinkish buff gray color with black spots. Its texture is even grained, coarse, with feldspars up to 0.8 inch and mica to 0.3 inch. Its constituents, in descending order of abundance, are: Pinkish buff potash feldspar (orthoclase) in twins and minutely intergrown with soda-lime feldspar (oligoclase-albite), also intergrown with quartz and kaolinized; amethystine quartz with cavities in sheets intersecting at right angles, those in the rift direction being very close together; slightly greenish gray soda-lime feldspar (oligoclase), also intergrown with quartz, kaolinized, and partly micacized, in cases inclosed in orthoclase; biotite (black mica), some of it chloritized. Accessory minerals are: Fluorite, allanite, zircon. Secondary: Kaolin, a white mica, chlorite, and limonite and hematite stain.

This is a coarse constructional granite with good rift.

The quarry, not operated since December 1, 1903, lies between the 645 and the 735 foot levels, measures about 400 feet N. 75° W. by 250 feet across and from 35 to 90 feet in depth. The top of the working face is 30 feet below the top of the hill.

The sheets, from 3 to 30 feet thick, are horizontal or dip low north and also south. Joints A, striking N. 30° E. and dipping 60° N. and 90°, are spaced 20 to 70 feet. Joints B, striking N. 70° to 80° W. and vertical, are spaced 2 to 50 feet. A geode of pegmatite with smoky amethystine quartz crystals an inch long was noticed. Rusty stain is from 1 to 8 inches thick on the sheets and up to 2 feet along the joints.

The plant consists of 11 derricks, 4 Lidgerwood hoisting engines, 6 Lidgerwood "skeleton engines," 2 Lambert engines, 2 air compressors (Rand No. 10), 6 large drills, 16 air plug drills, a locomotive engine, and 4 steam pumps.

Transportation is by a private siding, 1¾ miles long, from the main line of the Boston and Maine Railroad. (See fig. 23.)

This quarry was opened by the contractors for the Boston dry dock at the Charlestown Navy-Yard, in which the stone was used. It but recently passed into the hands of its present owners.

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The Fletcher & Lahey quarry is in the town of Madison, about 2½ miles southwest of Conway Corners and a mile about west of the main line of the Boston and Maine Railroad. Operators, Fletcher & Lahey, West Chelmsford, Mass.

The granite (specimens D, XXVIII, 37, b, d)—the more pinkish variety—is a biotite granite of light pinkish gray color, mottled with dark purplish gray and with small black spots. Its texture is even grained, coarse, with feldspars up to 0.7 inch and mica to 0.2 inch. Its constituents, in descending order of abundance, are a light pinkish gray potash feldspar (orthoclase, mostly twinned), minutely intergrown with soda-lime feldspar (oligoclase-albite) and considerably kaolinized; dark amethystine-smoky quartz with cavities; translucent slightly greenish white striated soda-lime feldspar (oligoclase) partly micacized; and biotite (black mica), some of it chloritized. Accessory: Magnetite and allanite. Secondary: Kaolin, a white mica, and chlorite.

An estimate of the mineral percentages, by the Rosiwal method, yields the following results with mesh of one-half inch and total linear length of 20 inches:

Estimated mineral percentages in Madison, N. H., granite.

Feldspars	67.20
Quartz	28.60
Mica (biotite)	4.20
	100.00

Mr. E. C. Sullivan, of the United States Geological Survey's chemical laboratory, finds that this granite contains 0.25 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates a content of 0.44 per cent of $CaCO_3$ (lime carbonate).

This is a coarse-textured constructional granite of warm tint, possessing marked contrasts of color, which come out strongly on the polished face (delicate pink, mottled with purplish smoke and dotted with black). The somewhat large mica scales are not favorable to the durability of the polish under long-continued outdoor exposure.

The less pinkish variety (specimen 37, a) is like the other except in that the orthoclase is more nearly cream colored. Apatite and zircon appear among its accessory minerals. Its contrasts are, if anything, a trifle more marked than those of the other.

The quarry, opened between 1888 and 1891, is at the east foot of a granite bluff 200 feet high, which also has a steep south side. It is about 500 feet square, with an extension on the bluff where there is a working face 100 feet high. Its depth is from 15 to 50 feet.

The sheets, from 2 to 20 feet thick, are horizontal but dip 10° E. on the east and on the bluff 10° E. to NE. There are two sets of joints: Set A, striking N. 80° W. and vertical, is spaced 5 to

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100 feet and forms a 10-foot heading in the northern half of quarry and another at the north wall. Set B, striking N. 15° E. and vertical, is spaced 5 to 100 feet and forms a heading on the east side. The rift is reported as horizontal and the grain as vertical, with N. 80° W. course. The pinkish variety occurs on the south side and the lighter on the north. Rare granitic dikes, 1 to 6 inches wide, consist of a groundmass of medium-gray shade and fine to medium texture, spangled with biotite and with porphyritic pinkish feldspars up to 0.4 inch. The groundmass consists of orthoclase, microcline, oligoclase-albite, quartz, and biotite. Rusty stain is from 1 to 4 inches thick on upper sheets, decreasing below. Joint faces are coated with epidote.

The plant consists of 4 derricks, 4 hoisting engines, an air compressor (capacity, 250 cubic feet of air per minute), 3 large drills, 9 air plug drills, and 3 steam pumps. The firm has a cutting plant at West Chelmsford, Mass.

Transportation is by a siding 1 mile long to the main line of the Boston and Maine Railroad.

The product is used almost entirely for bridges and buildings. In 1906 the firm was filling contracts for certain piers on the Boston and Maine Prison Point Street Bridge, at East Cambridge, Mass. (see p. 164), and also for a bridge at South Acton, Mass. Specimen monument: Dudley Porter memorial fountain, at Haverhill, Mass.

AUBURN.

The granite described in this section is quarried at a point 7 miles east of Manchester, in the township of Auburn, Rockingham County. Hitchcock's geological map of New Hampshire (1877 and 1885) shows at about that point a belt of "Huronian" schist and conglomerate on the southeast in contact on the northwest with the belt of "Winnepesaukee" gneiss (referred to on p. 144) as including the Concord granites. Both belts have a northeasterly trend. The Auburn granite apparently belongs to the same general granite area as the Concord granite.

The granite (specimens, D, XXVIII, 46, a, b), "deep-pink Auburn," is a quartz monzonite of medium pink-buff color with very fine black dots. Its texture is fine, with feldspar and mica up to 0.1 inch. Its constituents, in descending order of abundance, are: Slightly pinkish potash feldspar (orthoclase and microcline); almost, if not quite as abundant, clear to milk-white soda-lime feldspar (oligoclase), some of it kaolinized and micacized; smoky quartz; and biotite (black mica), some of it chloritized and bleached. Accessory minerals are: Magnetite, apatite, and zircon. Secondard: Kaolin, a white mica, chlorite, and hematite stain.

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The stone takes a fair polish, and the hammered face by its lightness offers not a little contrast to the rough and polished faces. It is used for monumental work.

The quarry is operated by W. H. Perry & Co., of Concord, N. H.

SUNAPEE.

The granite and diorite of the Sunapee quarry district are reported as occurring in vertical contact at a point about 2½ miles roughly east of Sunapee. Hitchcock's geological map of New Hampshire (1877 and 1885) shows very near this locality a contact between a belt of his "Atlantic system," which includes "Winnepesaukee" gneiss and the granite of Sunapee, Concord, and Milford, on the west, with a belt of his older "Laurentian" porphyritic gneiss on the east. The operator of the quarry states that the rift is horizontal in the granite but vertical in the adjacent diorite.

The granite (specimens, D, XXVIII, 47, a, b), "light Sunapee," is a biotite-muscovite granite of a light gray, slightly bluish color and very fine to fine texture, with feldspars up to 0.15 inch and mica to 0.1 inch. Its constituents, in descending order of abundance, are: Colorless, clear potash feldspar (microcline and orthoclase, the latter with hairlike crystals probably of rutile, both being intergrown with quartz circular in cross section); clear, colorless quartz, also with rutile needles; translucent to milk-white soda-lime feldspar (oligoclase-albite), somewhat kaolinized and intergrown with quartz; biotite (black mica), and muscovite (white mica). Accessory: Magnetite, garnet, zircon, and rutile. Secondary: Kaolin and carbonate.

This, as will be seen by comparing the descriptions, is finer grained than Concord granite. It lends itself well to fine carving. Its particles are too fine to afford contrasts. It takes a fair polish.

The "black granite" (specimen D, XXVIII, 48, a, b), "black pearl" or "dark Sunapee," is a quartz diorite of very dark bluish-gray color and fine, inclining to medium, texture, with feldspars up to 0.2 inch. Its constituents, in descending order of abundance, are: Clear, colorless to milk-white soda-lime feldspar (oligoclase-andesine to andesine), but little kaolinized, rarely intergrown with quartz; biotite (black mica); clear colorless quartz (possibly equal in amount to feldspar); and titanite. There is so much of this molasses-colored mineral present that it is easily seen with a loop. Accessory: Magnetite (ilmenite?), pyrite, allanite, and zircon. Secondary: Kaolin, epidote (about allanite), calcite, and hematite. It effervesces slightly with dilute muriatic acid.

When polished the rock appears black mottled with white. The polish is poor owing to the large size and abundance of mica. It

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shows magnetite and a little pyrite. The hammered face is light gray and thus is in marked contrast to both rough and polished faces. The stone is used for monuments and is suitable for inscriptions.

The quarry is operated by W. H. Perry & Co., of Concord, N. H.

RHODE ISLAND.

GENERAL STATEMENT.

The granite industry of Rhode Island centers at Westerly. Some of the quarries are near Westerly, others near Niantic. Westerly is at the extreme western edge of the State, 5 miles north-northeast of Watch Hill on the Atlantic shore, and Niantic is 4½ miles east-northeast of Westerly. (See map, Pl. I, and Stonington and Charlestown, R. I., topographic sheets of the United States Geological Survey.)

WESTERLY AND NIANTIC.

Topography.—Some of the Westerly quarries are on an east-west ridge about a mile northeast of the city. This ridge attains an elevation of 200 feet above sea level and 160 feet above the city. Others are about a mile southeast of Westerly on the 130-foot level, and one lies a mile east of it on the 100-foot level. The Niantic quarries lie from a mile south-southeast to 1¾ miles southeast of the village of Niantic, some being in the town of Westerly, and one in the town of Charlestown. (See fig. 24.)

General geology.—The granites of Westerly and the closely related granites of Niantic have been briefly described by Merrill, by Kemp, and by Rice and Gregory;[a] and in Gregory and Robinson's geologic map[b] of Connecticut the granite gneiss area into which the Westerly granites were intruded in the adjacent parts of Connecticut is shown.

According to these geologists, the "white" and "blue" fine-grained Westerly granites were intruded as dikes in a molten state into certain older granite gneisses (Sterling granite gneiss), which formed extensive parts of the surface along the Atlantic shore. The medium-grained reddish granite of the Redstone quarry northeast of Westerly and the very coarse gneisses exposed at the other quarries all belong to this granite gneiss formation. These granite gneisses were originally granites which had likewise been intruded into an earlier overlying gneiss, a metamorposed sedimentary rock ("Putnam gneiss," etc.) of which no remnants are reported as occurring at Westerly. Prior to the intrusion of the Westerly granite these older

[a] Merrill, G. P., Report of building stones: Tenth Census, vol. 10, 1885, p. 20. Kemp, J. F., Granites of southern Rhode Island and Connecticut, with observations on Atlantic coast granites in general: Bull. Geol. Soc. America, vol. 10, 1899, pp. 361–382, especially pp. 365–370, 375, 376, and pl. 35. Rice, W. N., and Gregory, H. E., Manual of the geology of Connecticut: Connecticut State Geol. and Nat. Hist. Survey, Bull. 6, 1906, pp. 115, 136, 152, 154, 155.

[b] Gregory, H. E., and Robinson, H. H., Preliminary geologic map of Connecticut, Sterling granite gneiss (24), also the accompanying Outline of the geology of the State: Conn. State. Geol. and Nat. Hist. Survey, Bull. 7, 1907, p. 36.

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granites had been subjected to an amount of lateral compression sufficient to crush, elongate, rearrange, and recrystallize their par-

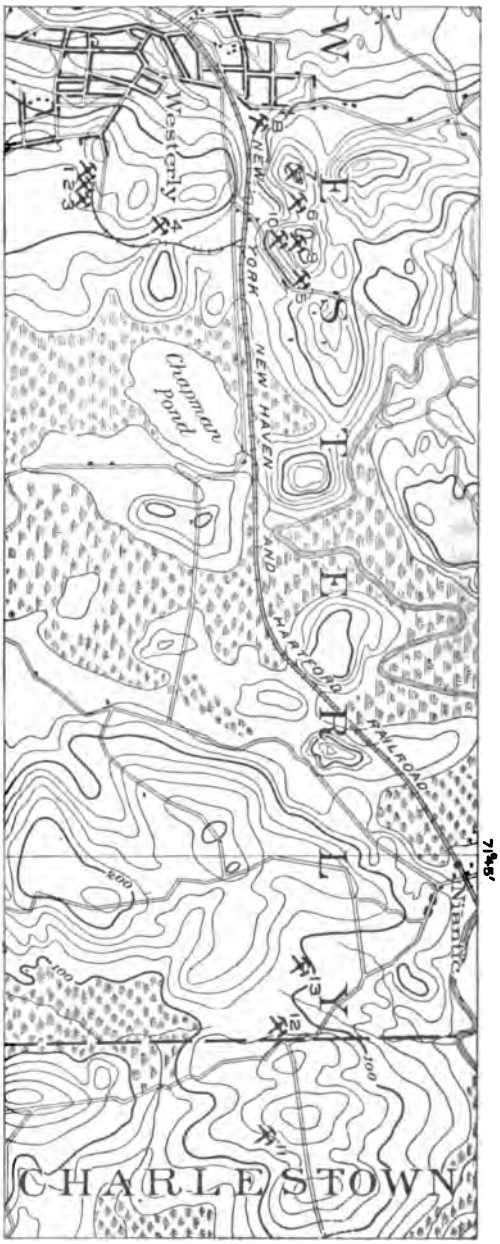

FIG. 24.—Map of vicinity of Westerly and Niantic, R. I., showing location of the granite quarries. 1, New England quarry, New England Granite Works. 2, Smith new east quarry, Smith Granite Company. 3, Smith old opening. 4, Catto quarry, Catto Granite Company. 5, Redstone quarry, New England Granite Works. 6, Smith north quarry, Smith Granite Company. 7, Calder & Carnie quarry. 8, Dixon quarry, Sweeney Granite Works. 9, Fraser quarry. 10, Chapman quarry. 11, Klondike quarry, Gourlay Granite Works. 12, Newall quarry, Joseph Newall & Co. 13, Crumb quarry, Crumb Quarry Company.

ticles and thus change them into a gneiss. The amount of this change is not always uniform. At some time prior to the intrusion

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of the Westerly granite the granite gneiss was traversed by pegmatite dikes. The Westerly granites themselves were later also traversed by pegmatite dikes and at a still later time by basic dikes. These dikes are probably of Triassic age, as are the trap ridges of New Haven and the Connecticut Valley. Thus the Westerly region bears records of at least five periods of igneous activity.

Geology of Westerly and Niantic quarries.—That the fine statuary granite is of later date than the coarser red granite (Sterling granite gneiss) is clear from their relations at the Redstone, Smith north, and Calder & Carnie quarries. That the red granite itself is older than a banded biotite gneiss follows from its containing inclusions of it. Northeast of Westerly the fine statuary granite was intruded into the red granite, but at the Smith and Catto quarries (figs. 25, 26) it or its associated fine blue granite was intruded into a finely banded biotite gneiss not unlike that in the red granite, and at the Klondike, Newall, and Crumb quarries, near Niantic (Pl. IX, *A*, and fig. 27), it was intruded into a porphyritic biotite gneiss, which may be simply a more gneissic phase of a coarser Sterling granite gneiss than that exposed at the Redstone and Dixon quarries. But the finely banded gneiss of the other quarries and of the inclusions resembles the inclusions in the Redstone granite and differs from that granite itself both by the absence of microcline and by the predominance of oligoclase or of oligoclase-andesine to andesine so as to indicate that these finely banded gneisses belong to another formation, possibly to the Putnam gneiss of Connecticut geologists. The strike of the banded biotite gneiss is N. 35° W. at the Smith quarry.

The fine Westerly granites appear in dikelike masses from 50 to 150 feet thick, striking N. 75°–90° W., and dipping 30°–45° about south. At the Smith quarry they are underlain by a parallel mass of aplitic granite of similar character, carrying also inclusions of finely banded biotite gneiss. At the Klondike quarry the granite has a flow structure striking N. 10°–20° W., intersecting the course of the apparent dike. It is uncertain whether these are granite dikes or protuberances from a broad intrusive mass which have become exposed by the erosion of the thinner parts of the overlying gneiss.

The phenomena at the quarries indicate the following as the probable order of geological events about Westerly: (1) A finely banded biotite gneiss forms the surface; (2) intrusion by the red granite of the hill northeast of Westerly with a northeasterly flow structure, and also by the gray granite of Niantic; (3) metamorphism of the red and gray granite converting it about Niantic into a porphyritic gneiss (Sterling granite gneiss); (4) intrusion of the Westerly and Niantic fine granites, in some places into the earlier banded biotite gneiss, in others into the more or less altered Sterling granite gneiss; (5) peg-

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matite and aplite dikes traverse both the Westerly granites and the Sterling granite gneiss, some in the latter, however, are connected with the intrusion of the finer granite; (6) a diabase dike traverses both the Westerly and the Sterling granite and the pegmatite dikes in the latter at the Redstone quarry. This occurred probably in Triassic time.

The chief joint course in the fine granites is N. 10°–25° E. but the following also occur: N. 35°–40° E., N. 50°–60° E., N. 10°–22° W., N. 45°–55° W. In the older red granite the courses are N. 35°–45° E. and N. 60° W. The rift is reported, in the fine granites, as either horizontal or inclined 10° north or south, and the grain as either vertical or 75° north, with an east-west or N. 65° W. or N. 70° E. course, in one instance with a dip of 45° S. 20° W., in another as scarcely perceptible. In the coarser granite the rift is reported as dipping 20° east or west. A compressive strain is reported as coming from the north and south, east and west, and northeast and southwest.

Description of Westerly granites.—The following summarizes the more detailed descriptions of specimens and thin sections, from both Westerly and Niantic quarries, given on pages 194–209.

"Westerly white statuary" granite is a quartz monzonite of more or less pinkish or buff medium-gray color, and of very fine even-grained texture, with slender feldspars not over 0.1 inch long and slender micas not over 0.15 inch long. Its constituents, in descending order of abundance, are: Pale smoky quartz; clear, colorless to milk-white soda-lime feldspar (oligoclase-albite to oligoclase); in nearly equal amount, slightly pinkish or cream-colored potash feldspar (microcline and orthoclase); and black mica. Magnetite and pyrite are among the accessory minerals, and calcite is among the secondary.

"Blue Westerly" granite is a quartz monzonite of more or less bluish medium-gray color, with fine black particles and of fine even-grained texture, with feldspars up to 0.1 or 0.2 inch and mica to 0.1 or 0.15 inch long. Its constituents, in descending order of abundance are: Clear to milk-white, pinkish or cream-colored soda-lime feldspar (oligoclase-albite to oligoclase); more or less transparent bluish or greenish potash feldspar (microcline and orthoclase); and black mica. Magnetite and pyrite are among the accessory minerals, and calcite is among the secondary.

"Red Westerly" granite is a biotite granite of reddish-gray color speckled with black and of even-grained medium, inclining to coarse, texture, with feldspars under 0.4 inch, exceptionally 0.5 inch, and mica up to 0.2 inch long. Its constituents, in descending order of abundance, are: Reddish potash feldspar (microcline and orthoclase-albite); and black mica. Both feldspars are in places stained

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red from hematite, resulting from the oxidation of magnetite particles, which with pyrite is among its accessory minerals. Secondary calcite is present.

Estimates of the mineral percentages in the statuary granite, obtained by applying the Rosiwal method to camera lucida drawings of parts of two thin sections enlarged 40 diameters, yield the following results, with mesh of 1 and 1.4 inches and total linear lengths of 40 and 33.6 inches.

Estimated mineral percentages in Westerly statuary granite.

Quartz	36.09
Oligoclase-albite to oligoclase (soda-lime feldspar)	30.63
Microcline and orthoclase (potash feldspar)	28.44
Biotite (black mica)	3.59
White mica	.50
Magnetite	.75
	100.00

The average diameter of the particles, obtained by the same measurements, is 0.175 millimeter or 0.0069 inch. Measurements of the larger particles in four thin sections of this granite, made with the micrometer, give the following figures: Microcline and orthoclase 0.50 to 0.95 millimeter, oligoclase 0.56 to 1.122 millimeters, biotite 0.39 to 0.56 millimeter, white mica 0.168 to 0.392 millimeter, quartz 0.50 to 1.122 millimeters, magnetite 0.112 to 0.224 millimeter. The feldspars, quartz, and biotite in their coarser particles thus range from 0.39 to 1.122 millimeters, or 0.015 to 0.0439 inch.

Two estimates of the mineral percentages in "Westerly blue" granite (pp. 195, 208), made in the same way,[a] average:

Estimated mineral percentages in Westerly blue granite.

Soda-lime feldspar (oligoclase-albite to oligoclase)	44.48
Quartz	25.28
Potash feldspars (microcline 11.03, orthoclase 9.26)	20.29
Biotite (black mica)	5.90
White mica	1.53
Magnetite	1.16
Pyrite	.05
Allanite and apatite	1.31
	100.00

The average diameter of the particles, obtained by the application of the same method to three Westerly blue granites, is 0.0099 inch, or about 50 per cent larger than that of the statuary.

An estimate of the mineral percentages in red Westerly granite will be found on page 200.

[a] As bearing upon other methods of making such estimates of the mineral percentages in Westerly granites see Williams, I. A., The comparative accuracy of the methods for determining the percentages of the several components of an igneous rock: Am. Geol., vol. 35, Jan., 1905, pp. 34–46.

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Kemp[a] gives two analyses of Westerly granite made by F. W. Love, then of Cornell University, which are repeated here for reference.

Analyses of Westerly granites by F. W. Love.

	Gray granite.	Red granite.
	Per cent.	*Per cent.*
SiO_2 (silica)	71.64	73.05
Al_2O_3 (alumina)	15.66	14.53
Fe_2O_3 (iron sesquioxide)	2.34	2.96
FeO (iron oxide)		
MnO (manganese oxide)	Trace.	Trace.
CaO (lime)	2.70	2.06
Na_2O (soda)	1.578	1.72
K_2O (potash)	5.60	5.39
H_2O (water)	.482	.29
	100.000	100.00

Kemp gives 2.654 as the specific gravity of the gray analyzed.

Messrs. Sullivan and Schaller, chemists, of the United States Geological Survey, find that 5 specimens of Westerly granites contain the following percentages of CaO (lime) soluble in hot dilute acetic acid, which indicate the presence of the percentages of $CaCO_3$ (lime carbonate) shown in the second column. All these granites effervesce slightly with cold dilute muriatic acid.

Lime and lime carbonate in Westerly granite.

Name of granite.	CaO.	$CaCO_3$.
White statuary	0.34	0.6
Blue Westerly	.176	.312
Red Westerly	.25	.446

The "white," really buff to slightly pinkish gray, and the "blue," really bluish gray, Westerly granites are strictly monumental granites, but the former may be called a statuary granite, as it lends itself to the most delicate carvings. The fineness of its texture becomes more apparent in comparing it with that of statuary marbles. Vogt classifies European marbles by texture in five groups:[b] Extremely fine, in which the particles measure from 0.02 to 0.03 millimeter; very fine (Carrara ordinary), from 0.1 to 0.3 millimeter; moderately fine (Carrara statuary), from 0.25 to 0.75 millimeter; somewhat coarse, from 0.75 to 2 millimeters, and moderately coarse, from 1 to 3 millimeters. West Rutland, Vt., statuary marble measures from 0.07 to 0.3 millimeter, averaging 0.15 by micrometer.[c] As the Westerly statuary granite averages by the Rosiwal method 0.175 millimeter, and its coarse particles by micrometer from 0.39 to 1.122

[a] Kemp, J. F., Granites of southern Rhode Island and Connecticut, with observations on Atlantic coast granites in general: Bull. Geol. Soc. America, vol. 10, 1899, p. 375.

[b] Vogt, J. H. L., Der Marmor, seine Geologie, Struktur, und seine mechanische Eigenschaften: Zeitsch. prakt. Geol., 1898, p. 12.

[c] Bull. U. S. Geol. Survey No. 195, 1902, p. 14.

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millimeters, its texture is but a trifle coarser than West Rutland statuary marble and between Carrara statuary and Vogt's "somewhat coarse" grade. It takes a high polish and its hammered surface is light, offering, as quartz monzonites generally do, a marked contrast of shade to the polished surface.

Although "blue Westerly" granite is 50 per cent coarser in texture than the "white Westerly statuary" it lends itself well to monumental and sculptural work, as is shown by Pl. IX, *B*. Its polish is not quite so high as that of the "white," owing to the larger size of its mica scales, but its contrast of shade is equally strong.

"Red Westerly" granite is used only for constructional purposes.

The Westerly quarries.—The New England quarry is nine-tenths of a mile southeast of the Westerly station and 100 feet above it. (See fig. 24.) Operator, The New England Granite Works, Westerly, R. I.

The granite is of two varieties: The first (specimens D, XXVIII, 1, f, i), "white Westerly statuary," is a quartz monzonite of very slightly pinkish medium-gray color, and of very fine even-grained texture, with very slender feldspars not over 0.1 inch long and slender mica scales rarely 0.1 or 0.15 inch long. The average diameter of all its particles, including the magnetite, as determined by the Rosiwal method, is 0.0069 inch or 0.175 millimeter, as given on page 192. Its constituents, in descending order of abundance are: Pale smoky quartz with hairlike crystals of rutile and a few cavities; clear colorless to milk-white soda-lime feldspar (oligoclase-albite to oligoclase), partly kaolinized and micacized; in almost equal amount, slightly pinkish or cream-colored potash feldspar (microcline and orthoclase), some of it intergrown with quartz circular in cross section; biotite (black mica), some of it chloritized and interleaved with white mica or else partially bleached; some separate muscovite may be present also. Accessory minerals are: Magnetite (ilmenite?), titanite, pyrite, allanite, apatite, zircon, and rutile. Secondary: Kaolin, one or two white micas, chlorite, and carbonate.

On the west side of a pegmatite dike referred to on page 196 this granite is decidedly pinkish, strictly a medium pinkish gray, owing, apparently, to hematitic stain in the kaolinized oligoclase. Some of the microcline is also kaolinized and micacized (specimen D, XXVIII, 1, e).

Estimates of mineral percentages in this stone have been given on page 192.

Mr. W. T. Schaller, chemist, of the United States Geological Survey, finds that it contains 0.34 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates a content of 0.6 per cent $CaCO_3$ (lime carbonate), the presence of which carbonate is shown by the microscope and by a slight effervescence with cold dilute muriatic acid.

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A compression test made for the firm at the United States Arsenal at Watertown, Mass., in 1907, with a cube of about 2-inch face, gave this granite an ultimate compressive strength of 39,750 pounds per square inch. The direction of rift or grain with reference to pressure was not noted.

The sculptural qualities of this stone have already been dwelt upon. The great fineness of its particles contributes to its high polish. The polished face shows minute particles of magnetite and a few of pyrite. It hammers light gray and the contrast between this and the shade of the polished face is somewhat marked.

The second variety (specimens D, XXVIII, 1, c, cc), "old blue Westerly," is a quartz monzonite of very slightly bluish medium-gray color with fine black particles. Its texture is even grained fine, with feldspars up to 0.2 inch and mica to 0.15 inch. Its constituents, in descending order of abundance, are: Clear to milk-white or pinkish soda-lime feldspar (oligoclase-albite to oligoclase), much of it kaolinized and micacized; pale smoky quartz with a few needle-like crystals, probably of rutile, and with cavities in sheets; clear to blue-greenish and grayish potash feldspar (orthoclase and microcline), intergrown with quartz, circular in cross section, and slightly micacized; biotite (black mica), some of it chloritized, and with needle-like crystals of rutile (?); muscovite or bleached biotite. Accessory: Magnetite (ilmenite?), pyrite, apatite, allanite, zircon, and rutile. Secondary: Kaolin, two white micas, chlorite, carbonate, and rarely hematite and epidote.

An estimate of the mineral percentages, obtained by applying the Rosiwal method to a camera lucida drawing of part of a thin section enlarged 40 diameters, yields the following results with a mesh of 1.7 inches, and total linear length of 42 inches.

Estimated mineral percentages in "blue Westerly" granite from the quarry of the New England Granite Works.

Quartz	21.15
Soda-lime feldspar (oligoclase-albite to oligoclase)	52.64
Potash feldspars (microcline 4.14, orthoclase 10.51)	14.65
Biotite (black mica)	5.52
White mica	3.05
Magnetite	1.71
Allanite	1.28
	100.00

No great value need to be attached to the figures for allanite, as a shifting of the mesh would have thrown it out altogether.

The average diameter of the particles obtained by the same method is 0.0112 inch.

Mr. E. C. Sullivan, chemist, of the United States Geological Survey, finds that this stone contains 0.20 per cent of CaO (lime) soluble in hot

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dilute acetic acid which indicates a content of 0.35 per cent of $CaCO_3$ (lime carbonate), the presence of which carbonate is also shown by the microscope and by a very slight effervescence with cold dilute muriatic acid.

A compression test made for the firm at the United States Arsenal at Watertown, Mass., in 1907, with a cube of about 2-inch face, gave it an ultimate compressive strength of 31,970 pounds per square inch. The direction of rift or grain with reference to pressure was not noted.

This stone takes a high polish, but the mica scales, being a little larger than in the "white statuary," show more on the surface. The polished face shows not a little magnetite in fine particles, with rare grains of pyrite. The combination of a slightly bluish with a slightly pinkish feldspar, both in fine particles, results in a peculiar gray in the polished face. The hammered face is light gray and in contrast to the shade of the polished surface.

The quarry, opened about 1860, measures about 300 feet in a west-northwest direction by 200 feet north-northeast, and from 40 to 80 feet in depth. Within 20 feet west-northwest of it is another opening, not used in 1906, of about the same size, which it was proposed to unite with the main opening so as to obtain a working face 600 feet long.

The sheets, from 6 inches to 12 feet thick, are horizontal but somewhat irregular, owing to incomplete development, "growing on." There are two sets of joints: Set A, striking N. 15°–25° E. and vertical, is spaced 8 inches to 30 feet, and forms a heading 15 to 20 feet wide on the west side, separating it from the older excavation, and another 5 to 10 feet wide on the east side, which divides this from the adjacent Smith quarry. Set B, striking N. 50°–55° W. and vertical, is spaced 18 inches to 30 feet. The rift is reported as horizontal and the grain as vertical with N. 65° W. course. There is a 2-inch pegmatite dike striking N. 37° E. and dipping 75° E., consisting of pink potash feldspar, amethystine quartz and muscovite; the feldspar is partly altered to light-green epidote. Pegmatite dikes also traverse the heading on the west side. Rusty stain is from 1 to 7 inches thick on the sheet surfaces. There is much kaolinization of feldspar and limonite stain adjacent to the pegmatite dikes. On the south-southwest wall the granite is in contact with a southerly-inclined overhanging mass of dark biotite gneiss with a vertical foliation. This is also crossed by pegmatite dikes. The line of contact between granite and gneiss is jagged in places. The relations on the north wall are now largely concealed by dumps, but their character is well exposed in the adjoining Smith quarry and they are described on page 198. The structural relations of the pinkish-gray and bluish-gray granite to one another are not clear. At one point on the south-southwest wall the former seems to underlie the latter and

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there seem to be also lateral changes in the color of both near the dike which are possibly caused by it. The width of the granite from north-northeast to south-southwest does not exceed 150 feet measured at right angles to dip.

The plant includes 6 derricks, 3 hoisting engines, 3 engines for hoisting and general work, a 10-ton locomotive crane, a small locomotive, 3 air compressors (capacity 540,250,125 cubic feet of air per minute), 3 large drills, 8 air-plug drills, 40 air-hand tools, 4 surfacers, 2 saws for stones 13 feet long, 4 lathes for stones 3 to 6 feet long, 7 polishers, a polisher for moldings, 2 polishing lathes for stones 4 feet long, 2 stone borers, and 3 steam pumps.

Transportation is by a siding from the New York, New Haven and Hartford Railroad. (See map, fig. 24.)

Ninety-eight per cent of the product is used in monumental work, the rest, "old blue," only in buildings, and the waste for paving; particularly, small blocks for electric roads. Specimen monuments: National monument, Gettysburg, Pa.; Antietam monument, Maryland. The Horne monument, with a 7 foot 6 inch figure of the statuary granite, Homewood Cemetery, Pittsburg, Pa. Pl. IX, *B*, shows lilies and passion flowers on the base of a recently finished cross of the "blue" stone. Specimen buildings of the "blue": Connecticut Mutual Insurance Building, Hartford; Mutual Life Insurance Building, Philadelphia.

The Smith quarry adjoins on the east the one just described, and is about nine-tenths of a mile southeast of Westerly station and 100 feet above it. (See fig. 24.) Operator, The Smith Granite Company, Westerly, R. I.

The granite consists of the identical two varieties, "Westerly white statuary" and "Westerly blue," already described from the New England quarry. Both are quartz monzonites; the first, a slightly pinkish medium gray of even-grained very fine texture; the second, a slightly bluish medium gray of even-grained fine texture. (For full descriptions see pp. 194, 195.)

The quarry, first opened in 1846, consists of two openings. The "New East quarry," separated from the New England quarry only by a heading, is 250 feet east-southeast by 200 feet across and 65 feet deep; the other, older one, contiguous to the last on the east, is about 400 feet east southeast by 125 feet across and 150 feet deep.

The sheets in the upper 25 feet are from 2 inches to 2 feet thick, and below that from 9 inches to 5 feet thick, and all horizontal. There is only one set of joints, which strikes N. 20°–22° E., is spaced 100 to 300 feet, and forms a 50-foot heading between the two openings, and a 5 to 10 foot one between the western opening and the New England quarry. The rift is reported as horizontal and the grain as vertical, with a N. 65° W. course. The apparent relations of the

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granite are shown in fig. 25. On the south-southwest the granite is overlain by a mass of dark-gray banded biotite-hornblende gneiss of somewhat fine texture, "black horse," which strikes N. 30° W. and dips 45° SSW. The rock contains much soda-lime feldspar (oligoclase-andesine to andesine), but no microcline. On the north-northeast the granite is apparently underlain at 45° by a mass of granite (quartz monzonite) of more or less pinkish-gray color and of somewhat fine texture with a variable amount of black mica, so as in places to resemble an aplite. It is also marked in places by dark brownish stains, one-quarter inch in diameter and an inch or so apart, which are due to the alteration of allanite particles into hematite and limonite. This rock contains many angular inclusions, large and small, of a somewhat finely banded biotite gneiss which itself contains lenses and dikes of pegmatite parallel to its schistosity and evidently formed before the intrusion of the quartz monzonite. The northward extent of this mass has not yet been determined. The foreman states that the "blue granite" at the bottom of the larger opening contained an inclusion 10 feet in diameter like the inclusions of gneiss above described. In this opening about 40 feet of blue intervene between the overlying gneiss and the white statuary, as shown in fig. 25, but in the smaller opening these relations are reversed. The entire width of the mass of blue and white granite appears to be between 80 and 100 feet, measured at right angles to its inclination. There can be no question as to the extension of these granites below, but whether they continue downward at the same angle or widen out horizontally under the gneiss mass on the south can only be determined by core-drilling. The heading which separates the two openings is much broken by subjoints parallel to it. For a thickness of 8 feet on the west it is altered to a dull greenish-reddish color. In thin section this shows the feldspars kaolinized, micacized, and chloritized, most of the biotite bleached, the magnetite passing into hematite and the pyrite into limonite. As its soda-lime feldspar is oligoclase-andesine, differing from that of the adjacent granite, this heading may be a transverse granite dike.

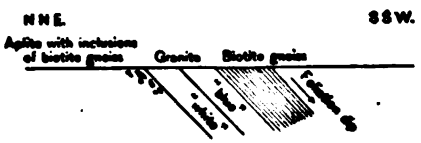

FIG. 25.—Structure at the Smith quarry, Westerly, R. I., looking east-southeast.

The plant comprises 8 derricks (one with a capacity of 50 tons), 8 hoisting engines, an engine for general work, 2 air compressors (capacity, 400 and 150 cubic feet of air per minute), 3 large air drills, 2 air plug drills, 27 air hand tools, 2 surfacers, a MacDonald surfacer, 2 stone lathes for stones 19 by 5 feet and 5 feet by 15 inches, a horizontal polisher, 5 vertical polishers, 2 polishing lathes, and 2 steam pumps.

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Transportation is by a siding from the New York, New Haven and Hartford Railroad, but paving stones are carted one-third mile to wharf on Pawcatuck River.

The product is nearly all used for monuments; the waste goes into paving blocks of various sizes. Specimen monuments: Equestrian statue of Washington erected by the United Order of American Mechanics at Allegheny, Pa.; Roger Williams monument at Roger Williams Park, Providence, R. I.; First Massachusetts Volunteer Infantry monument, Gettysburg, Pa.; Ohio State monument, Vicksburg, Miss.; Jay Gould mausoleum, Woodlawn Cemetery, New York; J. G. Fair mausoleum, San Francisco.

The Catto quarry is about a mile east-southeast of Westerly station, 60 feet above it, and one-half mile northeast of the Smith and New England quarries. (See fig. 24.) Operator, Catto Granite Company, Westerly, R. I.

The granite (specimen D, XXVIII, 9, a), "blue Westerly," is a quartz monzonite of very slightly bluish medium-gray color with fine black particles. It is a trifle more bluish than that of the New England quarry. Its texture is fine with feldspar and mica up to 0.1 inch, the former exceptionally 0.16 inch. It is thus a trifle finer than specimens D, XXVIII, 1, c, cc (p. 195). As its constituents are identical with those of that granite, they are not repeated here.

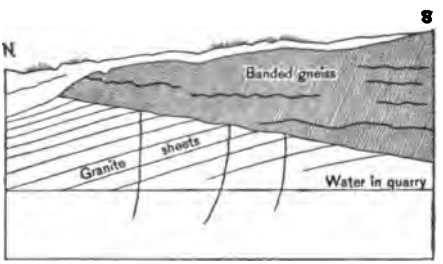

FIG. 26.—Diagram of east face of Catto quarry, Westerly, R. I., showing granite overlain by a mass of biotite gneiss, each with its own sheet structure. Length, 65 feet; height above quarry water, 50 feet.

The quarry, opened before 1886, is about 350 feet east-west by 200 feet across and from 75 to 100 feet in depth.

The sheets, from 6 inches to 10 feet thick, dip north at a low angle. But one set of joints occurs. This strikes N. 22° W., is vertical, spaced 3 to 50 feet, and is discontinuous below. The rift is reported as horizontal, and the grain as scarcely perceptible. Rusty stain measures up to an inch thick on sheet surfaces. The east face of quarry shows the relations of the granite to overlying banded gneiss. (See fig. 26.) This strip of gneiss extends the entire width of the quarry, with a foliation striking N. 65° W. and dipping 65° NNW. As the granite crops out in places above the gneiss this may be a very large inclusion, but probably from immediately under the original capping. The gneiss was so broken up here that hand specimens, half granite and half gneiss, with granite cutting the gneiss foliation can be readily obtained. The gneiss is rather fine grained and con-

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sists of dark-gray very biotitic bands, 0.1 to 0.3 inch wide, alternating with light-gray bands with little biotite and with very light ones without any. The dominant feldspar is oligoclase. There is no microcline.

The plant consists of 3 derricks, 3 hoisting engines, 2 steam drills, and 3 steam pumps.

Transportation is by a siding from the quarry to the main siding of New York, New Haven and Hartford Railroad.

In 1906 the firm was filling a contract for 500,000 paving blocks for Jersey City.

The Redstone quarry is less than 1½ miles east-northeast of Westerly station, at the east foot of an east-west ridge, one-fourth mile north of the New York, New Haven and Hartford Railroad. (See fig. 24.) Operator, the New England Granite Works, Westerly, R. I.

The chief granite of this quarry (specimens D, XXVIII, 2, b, h), "red Westerly," is a biotite granite of reddish-gray color speckled with black. Its texture is even grained, medium, inclining to coarse, with feldspars under 0.4 inch, exceptionally 0.5 inch, and mica to 0.2 inch. Its constituents, in descending order of abundance, are: Reddish potash feldspar (microcline and orthoclase), some of it slightly micacized, intergrown with quartz in vermicular structure, in places also with soda-lime feldspar; smoky quartz with hairlike crystals, probably of rutile, also with cavities in sheets with rift cracks parallel to them; cream-colored striated soda-lime feldspar (oligoclase-albite), kaolinized and micacized, and intergrown with quartz like the other; and biotite (black mica), some of it bleached. Accessory: Magnetite, pyrite, apatite, zircon, and rutile. Secondary: Kaolin, two white micas, hematite stain from magnetite particles, in places reddening both feldspars, and calcite.

An estimate of the mineral percentages by the Rosiwal method yields the following results with a mesh of one-half inch and total linear length of 33½ inches:

Estimated mineral percentages in "red Westerly" granite from the Redstone quarry.

Potash feldspar (microcline and orthoclase)	35.40
Quartz	29.87
Soda-lime feldspar (oligoclase-albite)	28.35
Biotite (black mica)	6.74
(Both feldspars, 63.39.)	
	100.00

An analysis of this granite by Love has been given on page 193.

Mr. W. T. Schaller, chemist, of the United States Geological Survey, finds that it contains 0.25 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates a content of 0.446 per cent of $CaCO_3$

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A. OVOIDAL BLOCK OF FINE STATUARY GRANITE (QUARTZ MONZONITE), PRODUCED BY WEATHERING WITHIN A HEADING AT REDSTONE QUARRY, WESTERLY, R. I.

Hammer 20½ inches long.

B. GRANITE QUARRY AT WEST FOOT OF BLACK MOUNTAIN, WEST DUMMERSTON, VT.

Showing thin sheets formed after opening of quarry and parted by a compressive strain operating about north and south. Hammer about 30 inches long; head 6 inches long.

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(lime carbonate), the presence of which carbonate is shown by the microscope and also by a slight effervescence with cold dilute muriatic acid.

A compression test made for the firm at the United States arsenal at Watertown, Mass., in 1907, with a cube of about 2-inch face, showed the first crack with 106,000 pounds and final fracture with 113,000 pounds, indicating an ultimate compressive strength of 28,540 pounds per square inch. The direction of rift or grain with reference to pressure was not noted.

The contrasts between the colors of the two feldspars come out strongly on the polished face which shows considerable magnetite and some pyrite. The size of the mica plate is not favorable to the durability of the polish in long-continued outdoor exposure. It is a constructional granite of warm tint.

The quarry, opened in 1880, measures about 850 feet, north-south by 250 feet east-west with a working face 100 feet high on west.

The sheets, from 1 to 20 feet thick, are somewhat irregular. In the upper part most of them dip 10° about west-northwest, a few are horizontal, but lower down all are so. At the south end the sheets are intersected by sharply curved partings ("toe nails"). There are inclusions of finely banded biotite gneiss resembling the capping at the Smith and Catto quarries. The rift is reported as horizontal and the grain as fairly defined and vertical with a N. 20° E. course. There is but one set of joints, and that strikes N. 35° E., dips 70° S. 35° E. to 90°, is spaced 15 to 50 feet, and forms a heading in the center of the quarry and a heading at extreme north end which is 40 feet wide. A dike 5 to 10 feet thick runs the whole length of the quarry, with a dip of 10° S., consisting of alternating reddish aplite and coarse pegmatite (reddish feldspar, smoky quartz, and biotite), some of the surfaces of which are coated with iridescent drusy hematite. Beneath this almost horizontal dike is a mass of unknown extent of fine pinkish-gray statuary granite (quartz monzonite) like that at Smith and New England quarries described on page 194. This reaches the surface at the north end of quarry, but excavations at the south end will not expose it until 1908. The ovoidal mass, shown in Pl. VIII, *A*, and described on page 58, came from the 40-foot heading which crosses this quartz monzonite at the north end of quarry. Near the center is a meandering vertical dike, 6 inches thick, of porphyritic olivine diabase, striking N. 45° E., probably of Triassic age. The dike rock is almost black with decomposing greenish crystals up to one-half inch long and with less abundant minute black crystals. It is incrusted with fibrous calcite and generally is slightly calcareous. In thin section the groundmass is of minute soda-lime feldspar crystals altered to white

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mica, a little black mica, and magnetite. The large greenish crystals are olivine altered to serpentine and epidote and veined with calcite. The black ones are augite. The rock has undergone alteration and weathering but not metamorphism. Ten feet west of this dike is a vertical meandering mass of coarse biotite schist about 6 inches thick, striking about northeast with foliation parallel to its course. In thin section this consists of biotite, muscovite, quartz, an opaque cream-colored mineral (probably kaolinized feldspar), calcite, and magnetite. This is probably a basic segregation or "knot" elongated in the direction of the flow. Rust stain on the sheet surfaces is up to 3, rarely 4, inches thick. A thin section of it shows both feldspars stained with limonite. It follows irregular cracks in the microcline and the quartz, as well as the boundaries between them. It proceeds in some cases clearly from the larger grains of magnetite and from biotite scales.

The plant consists of 4 derricks, 3 hoisting engines, 2 air compressors (capacity 750 and 500 cubic feet of air per minute), 2 large drills, 25 air plug drills, 2 surfacers, and 2 steam pumps.

Transportation is effected by a siding from the New York, New Haven, and Hartford Railroad not shown on fig. 24.

The product is used entirely for buildings. Specimens: Washington Life Insurance, American Exchange, American Tract Society, and Travelers Insurance Company buildings in New York.

The Smith North quarry is a mile N. 60° E. from the Westerly station, 120 feet above it, in a saddle on the east-west ridge north of the railroad. (See fig. 24.) Operator, The Smith Granite Company, Westerly, R. I.

The granite is of two sorts, "red Westerly," a medium-grained biotite granite of reddish-gray color identical with that of the Redstone quarry (specimens D, XXVIII, 2, b, h), described on page 200, and "pink Westerly" (specimen D, XXVIII, 4, a), which is a quartz monzonite of medium buff-gray color and of very fine even-grained texture, with feldspars mostly up to 0.057 inch, exceptionally 0.1 inch, and mica to 0.028, exceptionally 0.15 inch. It is identical in composition with the "white Westerly statuary," described on page 194, but is of more pinkish tint. Its soda-lime feldspar is oligoclase.

The quarry, opened before 1892, is about 200 feet east-west by 150 feet across, with a working face 75 feet high on the west and 25 feet on the east.

The sheets, from 6 inches to 10 feet thick, are lenticular, but very irregular and without uniform dip. The only set of joints strikes N. 10° E., is vertical or nearly so, and is spaced 20 to 40 feet. The rift is reported as dipping 10° S. and the grain 75° N. Sixty feet of the fine granite overlie the "red," the plane of their contact dip-

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ping 40°–50° about south. At the top of the working face a pegmatite dike 10 feet thick dips 45° S. Rusty stain is only 2 inches thick on sheet faces.

The plant consists of 3 derricks, 3 hoisting engines, a steam drill, and 3 steam pumps.

Transportation is by cartage of one-fourth mile to New York, New Haven and Hartford Railroad. The cutting of the fine stone is done at the company's sheds at Westerly.

The product, thus far, has consisted mostly of the pink statuary, the underlying constructional granite not being yet much exposed.

The Calder & Carnie quarry is nine-tenths mile N. 50° E. from the Westerly station, and 160 feet above it, on the western hump of the ridge north of railroad. (See fig. 24.) Operator, Calder & Carnie Westerly Granite Company, Westerly, R. I.

The granite (specimen D, XXVIII, 8, a), "Westerly pink statuary," is a quartz monzonite of medium pinkish-buff gray color, more pinkish than any of the other fine Westerly granites excepting specimen I, e, from next to the pegmatite dike in the New England quarry. Its texture is even grained, very fine, with feldspars not over 0.1 inch and mica still less. Its constituents are the same as those of the fine stone from the Smith north quarry, but with a little more hematite stain. The thin section shows carbonate, and the stone effervesces slightly with dilute muriatic acid. The quarry also yields the "red" constructional granite described on page 200.

The quarry, first opened in 1882 and recently reopened, is about 400 by 250 feet and 90 feet deep.

The sheets, from 6 inches to 8 feet thick, are horizontal and irregular. There are two sets of joints: Set A, striking N. 20° W., dipping 45° S. 70° W., spaced 2 to 8 feet, and discontinuous, forms a heading 10 feet wide in the center. One of these joints has subjoints, striking N. 30° W., one-half to 1 inch apart. Set B, striking N. 35°–40° E., dipping 80° N. 37° W. and 90°, is spaced 2 to 8 feet. The rift is reported as dipping north at a low angle and the grain as striking N. 70° E. and dipping 45° S. 20° W. The fine granite occurs here as a dike dipping 45° S. and 50 feet thick, with the medium grained "red" on both sides of it. It also contains pegmatite dikes parallel to its course. Light pinkish streaks (veinlets?) from 0.1 to 0.3 inch thick cross the quarry in the flow direction. In thin section these are found to consist of slightly altered granite. Both feldspars are much kaolinized, and the oligoclase is also much micacized; the biotite is chloritized and epidotized. The quartz particles are crowded with sheets of cavities (with liquid and vacuoles), and these are parallel to the sides of the veinlet as well as in line with streaks of kaolinization in its feldspars. Along joints A the granite is much reddened for 1 to 2 inches. In this reddish zone the feldspars are

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much kaolinized and micacized, the biotite is chloritized, epidote occurs, and the magnetite is altered to hematite, which has reddened the feldspars. Rusty stain is up to 4¾ inches thick on sheet surfaces.

The plant consists of 2 derricks, a hoisting engine, a steam drill, and pump.

Transportation involves cartage of three-fourths mile to a siding of the New York, New Haven and Hartford Railroad.

The product is used for monuments and buildings. In 1906 the firm had contracts for monuments for Quincy, Mass.; Manchester, N. H., and Erie and York counties, Pa.

The Dixon quarry is about one-half mile northeast of Westerly station at the west foot of the east-west ridge north of the railroad. (See fig. 24.) Operator, Sweeney Granite Works, Westerly, R. I.

The granite (specimen D, XXVIII, 7, a) is a biotite granite of medium buff-gray color with fine black particles. Its texture is medium inclining to coarse with feldspars up to 0.4 inch, exceptionally 0.5 inch, and mica to 0.15 inch. Its constituents, in descending order of abundance, are: Pinkish-gray potash feldspar (microcline and orthoclase), slightly kaolinized and intergrown with quartz and soda-lime feldspar; smoky quartz with cavities; greenish-gray striated soda-lime feldspar (oligoclase-albite), some of it much micacized and kaolinized; and biotite (black mica), some of it chloritized. Accessory: Magnetite, pyrite, apatite, allanite, and zircon. Secondary: Kaolin, two white micas, chlorite, limonite, hematite, and carbonate.

This is a constructional granite which is closely related to the "red" of the Redstone quarry, but in which the potash feldspars are less reddish and the soda-lime feldspars are greenish instead of cream colored.

The quarry consists of 3 openings: One 150 by 100 feet and 20 to 40 feet deep, one 100 by 75 feet and 40 feet deep, and another 100 by 50 feet and 10 to 30 feet deep.

The sheets, from 6 inches to 6 feet thick, are generally horizontal. There are 2 sets of joints: Set A, striking N. 45° E. and vertical, is spaced 50 to 100 feet and forms several headings. Set B, striking N. 60° W. and vertical, is spaced 50 feet and over and is less frequent than set A.

The plant comprises several derricks, hoisting engines, and a stone crusher which turns out material of 3 sizes.

Although the stone is adapted for buildings, only crushed stone was being produced in August, 1906.

The Frazer quarry is less than one-fourth mile west of the Redstone quarry, on the east-west ridge north of railroad. (See fig. 24.) No longer operated; owner, W. L. Frazer, Westerly, R. I.

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The granite (specimen D, XXVIII, 5, a), "Westerly statuary," is a quartz monzonite of medium buff-gray color with very fine black particles. Its texture is even grained, very fine, with feldspars and mica up to 0.1 inch. Its constituents are the same as those of the other fine-textured grayish-pinkish Westerly granites described on page 191.

The quarry is about 250 by 200 feet and over 50 feet deep.

The sheets, 6 inches to 5 feet thick, are horizontal. Joints, striking roughly about north and dipping 60°–70° W. or 90°, are spaced up to 20 feet and form headings on the east and west. There are inclusions of biotite gneiss on the dumps, also pieces of pegmatite consisting of pinkish microcline intergrown with quartz and oligoclase; smoky quartz, cream-colored oligoclase, and biotite.

The Chapman quarry is about south of the Frazer quarry near the foot of the ridge. (See fig. 24.) It is abandoned, but is mentioned here only because of its geological features.

A joint face forming the west wall and working face strikes N. 10° W. It is intersected at intervals of 1 to 3 feet by vertical joints striking N. 50° E. At the top is an inclusion of biotite gneiss 10 feet in diameter. Dipping 10° south across this face is a pegmatite dike about a foot thick. Between 20 and 30 feet below it is an aplite dike a few inches thick with like dip. The sheets are only from 1 to 3 feet thick, and the joint intervals are too short to make quarrying profitable. The granite is the fine-textured statuary (pinkish-gray) quartz monzonite, already described.

The Niantic quarries.—The Klondike quarry is in Charlestown, 1¾ miles southest of Niantic station and 5¾ miles about east of Westerly station. (See fig. 24.) Operator, Gourlay Granite Works, Westerly, R. I.

The granite (specimens D, XXVIII, 11, c, g), "blue-white Westerly," is a quartz monzonite of medium bluish-gray color with very fine black particles. Its texture is fine with feldspars up to 0.1, exceptionally 0.2 inch, and mica to 0.05, exceptionally 0.1 inch. Its constituents, in descending order of abundance, are: Clear to milk-white or cream-colored striated soda-lime feldspar (oligoclase), partly kaolinized and micacized. In some crystals the altered part is central; in others it forms a zone with unaltered feldspar within and without it; slightly smoky quartz with hairlike crystals, probably of rutile, and very few cavities; more or less transparent bluish potash feldspar (microcline and orthoclase, the first intergrown with quartz); and biotite (black mica), some of it chloritized. Accessory: Magnetite, titanite, pyrite rare, apatite, allanite, zircon, and rutile. Secondary: Kaolin, a white mica, and carbonate.

Mr. E. C. Sullivan, chemist, of the United States Geological Survey, finds that this granite contains 0.18 per cent of CaO (lime) soluble in

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hot dilute acetic acid, which indicates a content of 0.32 per cent of $CaCO_3$ (lime carbonate), the presence of which carbonate is also shown by the microscope and by a slight effervescence in cold dilute muriatic acid.

A compression test made for the firm at the United States Arsenal at Watertown, Mass., in 1907, with a cube of about 2-inch face, showed the first crack with 107,000 pounds, and final fracture with 118,000 pounds, showing an ultimate compressive strength of 29,500 pounds per square inch. The direction of rift or grain with reference to pressure was not stated.

This is a monumental granite of fine texture and bluish tint. Its texture is a little finer than that of the "old blue" of the New England quarry, and about the same as that of the Newall quarry (p. 207). It is more bluish than the former, not containing any pinkish feldspar, and, its mica particles being finer, it takes a higher polish. The polished face shows magnetite in fine particles, but scarcely any pyrite. There is quite a little contrast of shade between the hammered and polished faces.

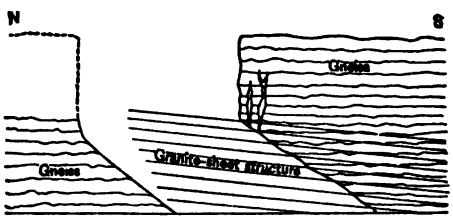

FIG. 27.—Approximate structure at the Klondike quarry, near Niantic, R. I.

The quarry, opened in 1897, is about 600 feet east-west by 100 feet across and from 75 to 100 feet deep. (See Pl. IX, *A*.) On the south side the stripping of drift increases from 5 feet in thickness at the west wall to 35 feet at the east wall, owing to the inclination of the rock surface.

The sheets, from 1 to 8 feet thick, dip generally 5° S. There is but one set of joints, which strikes N. 25° E., dips 70° W., and is spaced 5 to 50 feet. The rift is reported as horizontal, but feeble. A flow structure, indicated by streaks of black mica, strikes N. 10°–20° W. and dips west. There is a dike of aplite striking N. 25° E., dipping 70° W. The structural relations are shown in fig. 27 and Pl. IX, *A*. The granite appears to have reached the present surface in a dikelike mass, the sides of which dipped about 30° S., and cut a mass of porphyritic biotite gneiss, to be described beyond. The granite mass is about 75 feet thick, measured at right angles to its inclination. The foliation of the gneiss is not far from horizontal. Within the gneiss are dikes of pegmatite and aplite, which appear to begin at the granite contact meander and taper out upward. On the south side the sheet structure extends into the gneiss, as shown in Pl. IX, *A*. Fifteen feet below the gneiss the granite contains one or more angular

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A. CONTACT OF GRANITE WITH OVERLYING GNEISS ON WEST SIDE OF KLONDIKE QUARRY, NEAR NIANTIC, R. I.

Showing pegmatite dikes in the gneiss apparently starting from the granite surface; also sheet structure passing from granite into gneiss.

B. CARVING FROM WESTERLY BLUE GRANITE (QUARTZ MONZONITE), NEW ENGLAND GRANITE WORKS, WESTERLY, R. I.

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inclusions of finely banded biotite gneiss. The problem presented by the structure here is whether this belt of granite 75 feet thick is simply a dike of indefinite depth or a minor protuberance in the undulating surface of a wide granitic intrusion which became exposed by the erosion of the overlying gneiss where it was thinnest. The gneiss (specimen D, XXVIII, 11, a) is of very dark gray shade and fine to medium texture, but with porphyritic feldspars from one-half to 1½ inches in diameter, consisting of a light pinkish-buff potash feldspar (microcline and orthoclase), rimmed with milk-white soda-lime feldspar (oligoclase-andesine). The groundmass consists of the same potash feldspar, smoky quartz, the same soda-lime feldspar, and biotite. The granite is crossed at irregular intervals by pinkish and pyritiferous "streaks," veinlets from 0.1 to 0.4 inches wide, with a central thread of epidote. Their course is parallel to the joints. In thin section the soda-lime feldspars of these veinlets are much kaolinized and micacized. Rusty stain along sheets is from 1 to 6 inches thick. Some joint faces are coated with a thin film of calcite; others with epidote from the alteration of feldspar.

The plant consists of 7 derricks driven by 4 hoisting engines, 2 air compressors (capacity 550 cubic feet of air per minute each), 5 large drills, 25 air-plug drills, and 2 steam pumps.

Transportation involves a cartage of 2½ miles to New York, New Haven and Hartford Railroad.

The product is used entirely for monuments.

The Newall quarry is in the town of Westerly just west of the Charlestown line, 5¼ miles about east of Westerly station, and 1¼ miles southeast of Niantic station. (See fig. 24.) Operator, Joseph Newall & Co., Westerly, R. I.

The granite (specimens D, XXVIII, 6, a, c), "blue Westerly," is a quartz monzonite of medium bluish-gray color, with very fine black particles. Its texture is even grained, fine, with feldspars and mica up to 0.1 inch. Its constituents, in descending order of abundance, are: Clear to milk-white striated soda-lime feldspar (oligoclase), somewhat kaolinized and micacized; pale, smoky quartz, with few hairlike crystals, probably of rutile, and cavities; clear bluish to translucent potash feldspar (orthoclase and microcline), intergrown with quartz and slightly kaolinized; and biotite (black mica), some of it chloritized. Accessory: Magnetite, pyrite, allanite, zircon, and rutile. Secondary: Kaolin, a white mica, and carbonate.

An estimate of the mineral percentages, obtained by applying the Rosiwal method to a camera lucida drawing of part of a thin section enlarged 40 diameters, yields the following results with a 2-inch mesh and a total linear length of 38 inches.

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Estimated mineral percentages in "blue Westerly" granite from the Newall quarry near Niantic, R. I.

Soda-lime feldspar (oligoclase)	36.32
Quartz	29.38
Potash feldspars (microcline 17.91, orthoclase 8.00)	25.91
Biotite (black mica)	6.27
Magnetite	.60
Pyrite	.10
Apatite	.95
Allanite	.47
	100.00

Much weight should not be attached to the figures for apatite and allanite, for the mesh could have been shifted to avoid intersecting these particles, but their sum can be safely regarded as standing for the more abundant accessory minerals next to magnetite and pyrite.

The average diameter of all the particles obtained by the same measurements is 0.0087 inch.

Mr. W. T. Schaller, of the United States Geological Survey's chemical laboratory, finds that it contains 0.15 per cent of CaO (lime) soluble in dilute acetic acid, which indicates a content of 0.26 per cent of $CaCO_3$ (lime carbonate), the presence of which carbonate is also shown by the microscope and by a slight effervescence with cold dilute muriatic acid.

This is a fine-grained monumental granite susceptible of high polish and fine carving. It is of the same texture as the stone of the Klondike quarry, and a little finer than the blue of the New England and Smith quarries. Its shade is a trifle darker than that of the Klondike quarry. The polished face shows many minute particles of magnetite and a few of pyrite. There is marked contrast between the hammered and polished faces.

The quarry, opened in 1883, measures from 400 to 450 feet east-west by 250 feet across and from 50 to 100 feet in depth. In 1906 quarrying was confined to the deeper and wider part.

The sheets, from 1 to 9 feet thick, are horizontal at the east end, dip 10°–15° W. at the west end and 15° S. at the bottom. There are 2 sets of joints: Set A, striking N. 25° E., dipping 75° ESE., is spaced 5 to 200 feet. Set B, striking N. 45° W. and vertical, is exceptional. The rift is reported as dipping 20° about east, but in places west, and the grain as striking east-west and vertical. The granite occurs in a dikelike mass about 100 feet thick, dipping 45° S. and both underlain and overlain by "white horse," which here is a light pinkish-gray biotite gneiss consisting of light pinkish potash feldspar (microcline) in elongated crystals, smoky quartz, clear to milk-white oligoclase, and biotite. The foliation of this gneiss appears to strike about east-west and to dip with the surface 45° S. A pegmatite border separates granite from gneiss. Minute brownish veins

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traverse the gneiss. Rusty stain is up to 14 inches thick on sheet surfaces, and ferruginous water exudes from between them halfway down the surface.

The plant, including that at the firm's cutting shed at Westerly, comprises 5 derricks, 5 hoisting engines, a 20-ton traveling crane, an engine for general work, 2 air compressors (capacity 350 and 135 cubic feet of air per minute), 6 steam drills, 2 air plug drills, 48 air hand tools, 3 surfacers, 3 polishers, and a steam pump.

Transportation is effected by cartage of 1¼ miles to the New York, New Haven and Hartford Railroad at Niantic, and thence 4½ miles by rail to the cutting shed at Westerly.

The product is used exclusively for monuments. Specimens: Sarcophagus monument to Senator Sherman, Mansfield, Ohio; Obelisk to Gen. Lew Wallace, Crawfordsville, Ind.; W. L. Elkins and P. A. B. Widener mausoleums, Central Laurel Hill, Philadelphia; monument to J. D. Putnam erected by Fourteenth Wisconsin Regiment on the battlefield of Shiloh; reproduction of the elaborate Celtic cross of St. Martin in the island of Iona, erected by Mrs. McNeil in Rosedale Cemetery, Los Angeles, Cal.; also the T. M. Newall monument at Westerly, which has a delicate bas-relief of an entire poppy plant and a butterfly (design copyrighted).

The Crumb quarry is in Westerly, a mile S. 32° E. of Niantic station, and 5 miles about east of Westerly station. (See fig. 24.) Operator, The Crumb Quarry Company, Westerly, R. I.

The granite, "blue Westerly," is a quartz monzonite of medium bluish-gray color, with very fine black particles and even grained, fine texture, identical with that of the Newall quarry described on page 207.

The quarry, opened in 1857, is about 400 feet east-west by 125 feet across and 40 feet in depth.

The sheets, from 6 inches to 8 feet thick, are undulating horizontal. There are 2 sets of joints: Set A, striking N. 25° E., dipping 50°–70° WSW., is spaced 10 to 150 feet and forms a heading across the center. Set B, striking N. 60° E. and vertical, is exceptional and discontinuous. The rift is reported as horizontal, but with a "run" dipping low east and the grain as vertical east-west. The granite occurs in a dikelike mass, apparently continuous with that of the Newall quarry, which is about 850 feet east-southeast of it. It is about 100 feet thick and is underlain on the north by a gneiss, "white horse," with a foliation and surface dipping 20°–40° S. Owing to the quarry wall on the south being vertical, the dip of the foliation on that side could not be determined. This gneiss (specimen D, XXVIII, 12, b) is a light pinkish-gray biotite gneiss identical with that of the Newall quarry (p. 208). The light-pinkish feldspars (orthoclase and microcline) are in elongated lenses from 0.2 to 0.3 inch wide. The biotite

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is fine and sparse. Although the schistosity of the stone may possibly be great enough to impair its strength, its contrasts of color are very attractive. The granite is crossed by a 1-inch pegmatite dike dipping 45° E. Rusty stain is 10 to 15 inches thick along sheet surfaces. The faces of joints A are in places bright reddish and thinly coated with radiating pearly crystals of a silicate, stilbite (?).

The plant comprises 5 derricks (1 with 50 tons capacity), 3 hoisting engines, 2 steam drills, a polisher and engine, and 3 steam pumps.

Transportation requires cartage of 1¼ miles to the railroad at Niantic.

The product is used for monuments, which are made mostly in Quincy, Mass. Specimens: Alexander Thompson and Oliver Hazard Cooper monuments, Swan Point Cemetery, Providence; Rhode Island monument, Andersonville, Ga.

CLASSIFICATION OF THE GRANITES.

The "granites" described in this report fall into the following ten petrographical groups: Biotite granite, biotite-muscovite granite, muscovite-biotite granite, quartz monzonite, hornblende granite, biotite-hornblende granite, riebeckite-ægirite granite, riebeckite-ægirite-biotite granite, quartz diorite, and diabase porphyry.

For economic purposes these granites fall naturally into the two classes of *constructional* and *monumental granites*. Some granites, however, are noted for their susceptivity of a high polish or possess colors which only become effective on a polished face. Such are, therefore, termed *polish granites*. To this class belong also several of the constructional and monumental granites. Still other granites, by virtue of the contrast between their hammered or cut and their polished surfaces, are peculiarly adapted to inscriptions and are therefore classed as *inscriptional granites*. Here belong the quartz monzonites and diorites because of their large content of soda-lime feldspar. One of the monumental and inscriptional granites, from its remarkable fineness of texture, lends itself to the very finest carving and is therefore also classed as *statuary granite*. In the following table all the granites treated in this bulletin are grouped in these five economic classes. The trade name, the scientific name, the real general color and shade, and the texture of each stone are added in separate columns, and page references to the detailed descriptions and quarries are also given. In defining their general color reference to the black spots or spangles produced by the black silicates has been omitted.

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Economic classification of the chief commercial granites of Massachusetts, New Hampshire, and Rhode Island.

	Locality.	Trade name.	General color and shade.	Texture.	Scientific name.	Described on page —
Constructional.	Milford, Mass.	Milford pink	Light to medium pinkish, or pinkish-greenish gray	Medium to coarse, slightly gneissoid.	Biotite granite	75
	Quincy, Mass.	Extra light	Light pea-greenish gray	Medium to coarse	Riebeckite-ægirite granite	112
	Rockport, Mass.	Rockport gray, Bay View gray.	Medium gray	do	Hornblende granite	126, 128, 137
	Rockport, Mass.	Babson farm	Somewhat dark greenish gray	do	do	132
	Concord, N. H.	Concord granite	Medium bluish gray	Fine to medium, somewhat porphyritic.	Muscovite-biotite granite	146
	Redstone, N. H.	Redstone red granite.	Light pink mottled with dark gray	Coarse	Biotite granite	179
	Madison, N. H.	Fletcher and Lahey	Light pinkish gray mottled with dark purplish gray	do	do	185
	North Conway, N. H.	White Mountain quarry.	Medium pinkish-buff gray	do	do	184
	Milford, N. H.	Milford, N. H., granite.	Medium bluish gray, light gray, light buff-gray	Fine to medium	Quartz monzonite	160, 161, 163
	Westerly, R. I.	Red Westerly	Reddish gray	Medium to coarse	Biotite granite	191
Monumental.	Quincy, Mass.	Quincy dark and extra dark.	Dark gray (or bluish, greenish, purplish) to very dark bluish or purplish gray.	Medium to coarse	Riebeckite-ægirite granite	91
	Becket, Mass.	Chester dark and light	Medium bluish gray and medium-dark bluish gray	Fine	Muscovite-biotite granite	141
	Milford, N. H.	Milford, N. H., granite	Light gray, light to medium buff, or bluish gray	Fine (0.011 inch)	Quartz monzonite	164, 167, 168
	Milford, N. H.	Dark blue New Westerly and Souhegan.	Dark gray	Fine (0.0084 inch)	do	171, 176
	Milford, N. H.	New Westerly blue	Medium bluish gray	Fine (0.009 inch)	do	173
	Sunapee, N. H.	Light Sunapee	Light slightly bluish gray	Very fine to fine	Biotite-muscovite granite	187
	Auburn, N. H.	Deep pink Auburn	Medium pink buff	Fine	Quartz monzonite	186
	Westerly, R. I.	Blue Westerly	Bluish medium gray	do	do	191
	Westerly, R. I.	White and pink Westerly.	Pinkish or buff medium gray	Extremely fine (0.0069 inch).	do	191, 194
Polish granite.	Quincy, Mass.	Quincy dark, extra dark.	Dark gray (or bluish greenish, purplish) to very dark bluish or purplish gray.	Medium to coarse	Riebeckite-ægirite granite	107, 109
	Quincy, Mass.	Quincy gold leaf	Medium bluish gray with yellow brown spots	do	do	115
	Rockport, Mass.	Rockport and Bay View gray.	Medium gray	do	Hornblende granite	126, 128, 137
	Rockport, Mass.	Bay View green and Rockport green.	Olive gray	do	do	135
	Rockport, Mass.	Bay View dark (prospect).	Dark brownish gray	do	Riebeckite-ægirite-biotite granite.	139
	Rockport Mass.	Pigeon Cove porphyry	Black ground with medium gray crystals	Fine matrix and large porphyritic crystals.	Diabase porphyry	139
	Madison, N. H.	Fletcher and Lahey	Light pinkish gray mottled with dark purplish gray	Coarse	Biotite granite	185
	Redstone, N. H.	Redstone red granite.	Light pink mottled with dark gray	do	do	179
	Redstone, N. H.	Redstone green granite.	Dark yellow-greenish gray	do	do	182

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Economic classification of the chief commercial granites of Massachusetts, New Hampshire, and Rhode Island—Continued.

	Locality.	Trade name.	General color and shade.	Texture.	Scientific name.	Described on page—
Inscriptional.	Milford, N. H.	Dark blue New Westerly and Souhegan.	Dark gray	Fine (0.0084 inch)	Quartz monzonite	168, 171
	Sunapee, N. H.	Black pearl	Very dark bluish gray	Fine to medium	Quartz diorite	187
	Westerly, R. I.	Blue Westerly	Bluish medium gray	Fine (0.0099 inch)	Quartz monzonite	191
	Westerly, R. I.	White and pink Westerly.	Pinkish or buff-medium gray	Extremely fine (0.0069 inch).	do	191, 194
Statuary.	Westerly, R. I.	Westerly white statuary.	Buff medium gray	Extremely fine (0.0069 inch).	Quartz monzonite	191, 194

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COMMERCIAL VALUE OF THE GRANITES.

These granites represent quite a range in commercial value—from 25 cents to $3.25 per cubic foot. The following prices were obtained from the larger concerns as current in 1906. All are f. o. b. and per cubic foot in the rough.

Constructional granites.—*Milford, Mass.*, pink, in blocks up to 10 tons, $0.60 to $0.70. Foundation and bridge rubble work, $0.25. *Quincy*, light, for bases and hammered work, ordinary sizes, $0.50 to $0.85. Extra light, for bridge work, without reference to size, $0.35. *Rockport*, gray, ordinary sizes (3 to 15 feet long, 1½ to 4 feet wide, and 1½ to 3 feet high), best quality, $0.50. *Concord*, blocks under 9 feet square in base, $0.60. *Redstone, N. H.*, red, ordinary sizes, $0.40 to $0.50. *Milford, N. H.*, dimension stone in blocks up to 100 cubic feet, $0.40. *Westerly*, red, ordinary sizes, $0.60.

Monumental granites.—*Quincy*, medium, in blocks up to 40 cubic feet, $1 to $1.10; 40 to 55 cubic feet, $1.15. Dark, in blocks up to 40 cubic feet, $1.30 to $1.35; 40 to 55 cubic feet, $1.40. Extra dark, in blocks up to 40 cubic feet, $1.60. *Becket* (*Chester*), in blocks up to 40 to 50 cubic feet, $1.30 to $1.40. *Redstone, N. H.*, green, ordinary sizes, $0.65 to $0.75. *Milford, N. H.*, in blocks up to 10 cubic feet, $0.75 to $1.25, averaging $0.85. *Westerly*, blue, in blocks up to 10 cubic feet, $1.10 to $1.15. Up to 50 to 60 cubic feet, $2.60 to $2.75. White and pink statuary, in blocks up to 10 cubic feet, $1.10 to $1.25. Up to 50 to 60 cubic feet, $2.70 to $3.25. When the *Milford, Mass.*, pink is ordered finished for ornamental work the following prices prevail: Rock-faced ashlar building work, $1.50. Cut building work, $3.50. Polished building work, $6. Cut monumental work, $7. Polished monumental work, $10.

STATISTICS OF GRANITE PRODUCTION.

By Altha T. Coons.

In this section is shown the value of the stone produced at Becket, Chester, Milford, Pigeon Cove, Rockport, Quincy, and West Quincy, Mass., at Concord, Milford, and Redstone, N. H., and at Niantic and Westerly, R. I., by uses, and the total value of the production of each State from 1902 to 1906.

The figures in the following tables represent the selling value of the stone to the quarrymen, exclusive of any freight charges. When the stone is cut or dressed by the quarrymen and sold in this manner the value of the dressed stone is given. This applies especially to the stone quarried and sold for use as building and monumental stone.

The principal uses of the stone as shown in the following tables are for building stone, rough and dressed, and monumental stone, rough

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and dressed. Under stone sold for "other" purposes is included stone for curbstone, flagstone, some used for jetty purposes, stone posts, covers, a small quantity of crushed stone, and stone for various other rough work.

The total value for each State includes stone of all classes, rough and dressed building and monumental stone, flagstone, curbstone, riprap, rubble, crushed stone, and stone sold for various other purposes. A large quantity of trap rock quarried in Massachusetts and used chiefly for crushed stone is not included in the Massachusetts State total.

Production of granite by uses in the granite areas of Chester, Becket, Milford, Pigeon Cove, Rockport, Quincy, and West Quincy, Mass., and the value of the production of the entire State from 1902 to 1906.

Uses.	1902.	1903.	1904.	1905.	1906.
Rough building	$75,461	$88,900	$56,301	$85,796	$93,726
Dressed building	559,351	364,788	556,478	485,448	1,563,044
Rough monumental	468,016	357,449	319,448	396,187	346,311
Dressed monumental	290,678	231,375	201,877	187,361	239,310
Paving blocks	140,214	211,279	212,254	175,712	132,254
Rubble and riprap	73,011	91,951	67,962	35,085	24,476
Other	137,672	90,700	86,559	50,563	55,747
Total	1,744,403	1,436,442	1,500,879	1,416,152	2,454,868
State total[a]	3,080,857	2,351,027	2,554,748	2,251,319	3,327,416

[a] This does not include trap rock, used for road metal, etc.

Production of granite by uses in the granite areas of Concord, Milford, and Redstone, N. H., and the value of the production of the entire State from 1902 to 1906.

Uses.	1902.	1903.	1904.	1905.	1906.
Rough building	$67,704	$33,154	$32,733	$15,752	$29,622
Dressed building	272,385	239,201	367,610	178,757	198,931
Rough monumental	32,727	47,774	63,962	88,414	49,825
Dressed monumental	233,647	204,937	199,538	171,099	102,296
Paving blocks	28,001	34,907	40,045	48,484	76,229
Rubble and riprap	5,169	7,283	1,685	1,759	5,886
Other	25,996	38,707	23,378	35,866	58,689
Total	665,629	605,963	728,951	540,131	521,478
State total	1,147,097	854,513	927,487	838,371	818,131

Production of granite by uses in the granite areas of Niantic and Westerly, R. I., and the value of the production of the entire State from 1902 to 1906.

Uses.	1902.	1903.	1904.	1905.	1906.
Rough building	$4,478	$4,275	$6,225	$250	$100
Dressed building	80,967	101,914	203,649	62,688	184,614
Rough monumental	111,502	111,308	118,236	134,063	159,525
Dressed monumental	438,472	359,618	153,930	203,267	171,700
Paving blocks	13,884	36,634	41,791	79,641	25,332
Other	3,364	2,298	3,123	5,538	5,988
Total	652,667	616,047	526,954	485,447	550,319
State total	734,623	710,291	684,952	556,304	622,512

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CONCLUSIONS.

In reviewing the very numerous details brought together in the preceding pages several general ideas will impress themselves upon the reader: First, the long and complex geological history of the rock masses which are being quarried. Next, the very intricate microscopic character of the various granites described, both in their mineral composition and texture and in the changes which have taken place in them. Then, also, the great ingenuity shown in the various mechanical devices for quarrying the stone, and especially in the modern pneumatic machinery for working and finishing it; and, finally, the architectural and sculptural skill displayed in the structures and monuments made of it. Among the more notable of those made or being made of these granites are: The Pennsylvania Railroad terminal at New York, the Congressional Library, the Cambridge and Boston bridge, the Bunker Hill Monument, and the National Monument at Gettysburg.

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GLOSSARY OF SCIENTIFIC AND QUARRY TERMS.

Accessory minerals in granite are original constituents of the rock, found only in small, often only in microscopic quantity.

Acidic. A term applied to rocks in which silicic acid (silica) or quartz predominates.

Allanite. An opaque black mineral (silicate), brown in thin section, one of the primary less common accessory constituents of granite, which contains from 12 to 17 elements, including 6 of the rarer ones. For analyses see Dana, E. S., System of Mineralogy, 6th ed. 1892. pp. 522–526.

Anticline. A term applied to granite sheets or sedimentary beds that form an arch.

Aplite. Fine-grained granite, usually occurring in dikes and containing little mica and a high percentage of silica.

Basic. A term applied to rocks in which the iron-magnesia minerals and feldspars with lime and soda predominate, such as diabase or basalts.

Black horse. Term used by quarrymen in Rhode Island to denote a dark biotite gneiss in contact with the granite.

Blind seams. Quarrymen's term for incipient joints.

Bowlder quarry. One in which the joints are either so close or so irregular that no very large blocks of stone can be quarried.

Channel. A narrow artificial incision across a mass of rock, which, in the case of a granite sheet, is made either by a series of contiguous drill holes or by blasting a series of holes arranged in zigzag order.

Cleavage, when applied to a mineral, designates a structure consequent upon the geometrical arrangement of its molecules at the time of its crystallization.

Close jointed. A term applied to joints that are very near together.

Crocus. A term used in the Milford, N. H., quarries to denote gneiss or any other rock in contact with granite.

Crush-border. A microscopic granular structure sometimes characterizing adjacent feldspar particles in granite in consequence of their having been crushed together during or subsequent to their crystallization.

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CUT-OFF. Quarrymen's term for the direction along which the granite must be channeled, because it will not split. Same as "hardway."

DENDRITES. Plantlike crystallization of iron or manganese oxides on the surfaces of fissures in any rock or mineral. Frost crystals on window panes are of like character.

DIKE. A mass of granite, diabase, basalt, or other rock which has been erupted through a narrow fissure.

DIMENSION STONE. A term applied to stones that are quarried of required dimensions.

DIP. The inclination from the horizon, given in terms of degrees, of a sheet, joint, heading, dike, or other structural plane in a rock.

DRIFT. Sand and bowlders deposited by the continental glacier.

DRUMLIN. Oval hillock of clay and bowlders formed beneath the ice sheet of the glacial epoch.

EROSION. The wearing away of portions of a rock by such natural agencies as stream or ice action.

EXFOLIATION. The peeling of a rock surface in sheets owing to changes of temperature or other causes.

FAULTING. The slippage of a rock mass or masses along a natural fracture.

FLOW-STRUCTURE. The parallel arrangement of the minerals in granite or other igneous rock in the direction of its flowage during its intrusion.

GEODE. A rock cavity lined with crystals. Geodes in granite are attributed to steam or gas bubbles.

GRAIN in granite is practically the direction in which the stone splits "next easiest," the "rift" being that in which it splits most readily.

GROUT. A term applied to the waste material of all sizes obtained in quarrying stone.

GROW-ON. Quarrymen's term to designate the place where the sheet structure dies out, or the place where two sheets appear to grow onto one another.

HARD-WAY. The direction at right angles to both rift and grain in which granite does not split readily. (See Cut-off.)

HEADING. A collection of close joints.

HEADING-SEAM. See Joint.

HEMATITE. An oxide of iron (Fe_2O_3) which when scratched or powdered gives a cherry-red color.

IGNEOUS. A term applied to rocks that have originated in a molten condition.

JOINTS. More or less steeply inclined fractures which cross the granite sheets and which are attributed to various stresses.

KAOLIN. A hydrous silicate of alumina derived from the alteration of feldspar.

KAOLINIZATION. The process by which a feldspar passes into kaolin.

KNOTS. A term applied by quarrymen to dark gray or black objects, more or less oval or circular in cross-section, which are segregations of black mica or hornblende formed in the granite while in a molten state. English quarrymen call them "heathen."

KNOX HOLE. A circular drill hole with two opposite vertical grooves which direct the explosive power of the blast.

LEWIS HOLE. An opening made by drilling two or three holes near together and chiseling out the intervening rock.

LIMONITE. A hydrous oxide of iron ($2Fe_2O_3$, $3H_2O$); a hydrated hematite, which, when scratched or powdered, gives a brownish rust color.

MATRIX. The general mass of a rock which has isolated crystals; sometimes called groundmass.

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MILLIMETER. French decimal lineal measure, the thousandth part of a meter or the tenth part of a centimeter. It is equivalent to nearly 0.04 inches, the meter being $39\frac{1}{3}\frac{9}{7}$ inches.

MONOLITH. A column or monument of one stone.

MOTION. A term used in granite regions to designate small paving-block quarries.

OPHITIC. A term applied to microscopic rock texture to designate a mass of longish interlacing crystals, the spaces between which have been filled with minerals of later crystallization.

OREÏ. A term applied in the Quincy quarries to Quincy granite which has been rendered valueless by the alteration of its ægirite particles.

PEGMATITE. A very coarse granite occurring in irregular dikes or lenses in granites and some other rocks.

PLAGIOCLASE. A term applied to all those feldspars that are not potash feldspars.

POLARIZED LIGHT. Light whose vibrations, unlike those of ordinary light, which are in all directions, are in only one plane. Polarized light is used in the microscopic study of rocks.

PORPHYRITIC. A term applied to rock texture to designate the presence of isolated crystals in a general mass (matrix or groundmass) of finer material.

PSEUDOMORPH. Signifies false form, and designates a crystal in which, owing to various chemical changes, the original mineral has been more or less replaced by others. The form of the crystal no longer corresponds to the mineral.

QUARTZ MONZONITE. Technical designation for a granite in which the percentages of soda-lime and of potash feldspar are nearly the same or in which the former exceeds the latter. In ordinary granites the amount of soda-lime feldspar is relatively small.

RANDOM STONE. A term applied by quarrymen to quarried blocks of any dimensions. (See definition of dimension stone.)

RIFT. A quarrymen's term to designate an obscure microscopic cleavage in granite which greatly facilitates quarrying.

RUN. A term used by quarrymen in connection with "rift," apparently to denote the course of the deflection of the rift due to gravity, strain, or other not yet understood cause.

SALT-HORSE. Quarrymen's term for aplite.

SAND SEAMS. Quarry term for more or less minute veins or dikes of muscovite (white mica) with some quartz, in cases also with feldspar. (See p. 51.)

SAND STREAKS. Same as sand seams.

SAP. Quarrymen's term for ferruginous discoloration along sheet or joint surfaces.

SCHIST. A rock made up of flattish particles arranged in rough parallelism, some or all of which have crystallized under pressure.

SCHISTOSITY. The quality of being like a schist.

SEAM. Quarrymen's term for joint.

SECONDARY MINERALS. Minerals whose presence is due to the alteration of the original minerals.

SEDIMENTARY. A term designating those rocks that consist of particles deposited under water.

SEGREGATION. The scientific term for "knot;" a collection of material separated from other material. A VEIN OF SEGREGATION is one formed by the filling of a fissure with mineral matter originating in the surrounding rock.

SERICITE. A more or less fibrous form of muscovite (potash mica), often resulting from the alteration of feldspar.

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SHAKES. Quarrymen's term to designate a somewhat minute close-joint structure, which forms along the sheet surface as a result of weathering.

SHEET QUARRY. A quarry in which the granite lies in sheets, crossed by wide-spaced steep joints.

SLICKENSIDES. The polished and grooved faces of a joint or bed caused by motion and friction.

SPECIFIC GRAVITY. The weight of a rock or mineral compared to that of a body of distilled water of the same bulk.

STRAIN-SHEET. Quarrymen's term for granite sheets produced by present compressive strain.

STRATIFIED. A term applied to rock consisting of originally horizontal beds or strata.

STRIKE. The direction at right angles to the inclination of a plane of bedding, a sheet, or joint, etc.

STRIPPING. The material (sand, clay, soil, etc.) overlying a rock of economic value, which must be removed before quarrying.

SUBJOINT. Minor joints diverging from or parallel to the regular joints.

SYNCLINE. A geological term for the trough part of a wave-like sheet or bed of rock.

TILL. A mixture of clay and bowlders deposited by glaciers.

TOEING-IN. Quarrymen's term for the wedging in of the end of a granite sheet under an overhanging joint, probably in consequence of the faulting of the sheets along the joint. It is also applied to the overlapping of lenticular sheets.

"TOE NAILS." Curved joints intersecting the sheet structure, in most cases striking with the sheets, in some differing from them in strike 45° or more.

TWIN CRYSTALS. Two adjacent crystals which have formed with the poles of their main axes in opposite or different directions.

WEATHERING. The decomposition of a rock owing to the action of the weather.

WHITE HORSE. Term used by quarrymen to denote a light-colored gneiss, aplite, or pegmatite.

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